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Peters et al.

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(54) **FOAMED COMPOSITIONS FOR REDUCING FREEZE-THAW HEAVE RISK, AND METHODS OF UTILIZING AND PRODUCING THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(51) **Int. Cl.**
C04B 18/06 (2006.01)
C04B 18/08 (2006.01)

(52) **U.S. Cl.**
USPC **106/705**; 106/DIG. 1

(58) **Field of Classification Search**
USPC .... 106/705, DIG. 1
See application file for complete search history.

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(57) **ABSTRACT**

A composition and method for reducing freeze-thaw heave risk over flash-filled voids are disclosed. A composition can include cementitious fly ash, water and cellular foam. The composition can optionally include a filler, e.g., Type F fly ash, or additional desired components. A method can include mixing the desired composition and applying the composition to a void. The method can optionally include determining the desired composition based on various factors.

21 Claims, 15 Drawing Sheets

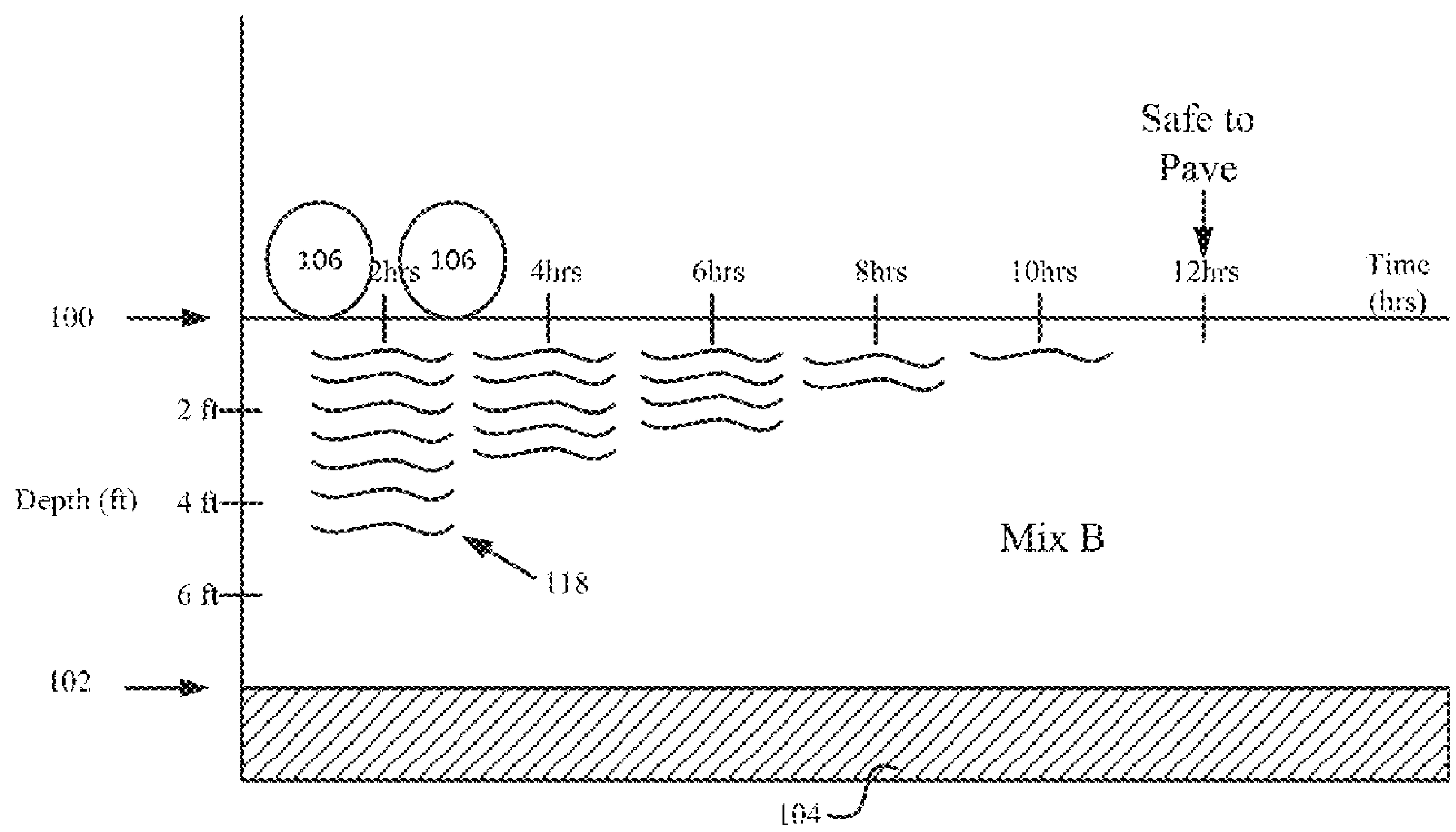

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FIG. 1

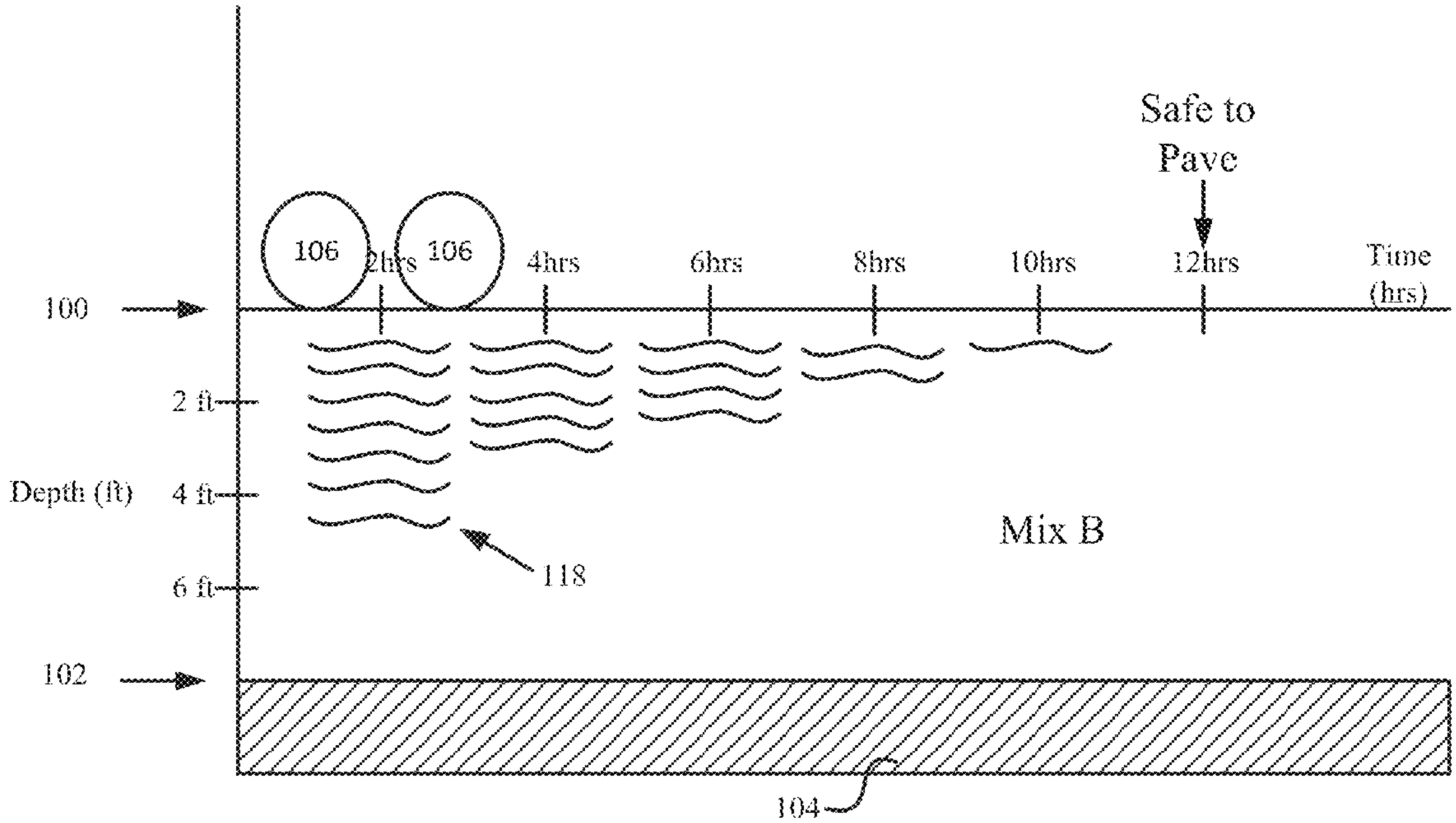

Safe to
Pave
106
106
2hrs
4hrs
6hrs
8hrs
10hrs
12hrs
Time
(hrs)
100
2 ft
Depth (ft)
4 ft
6 ft
118
Mix B
102
104

FIG. 2

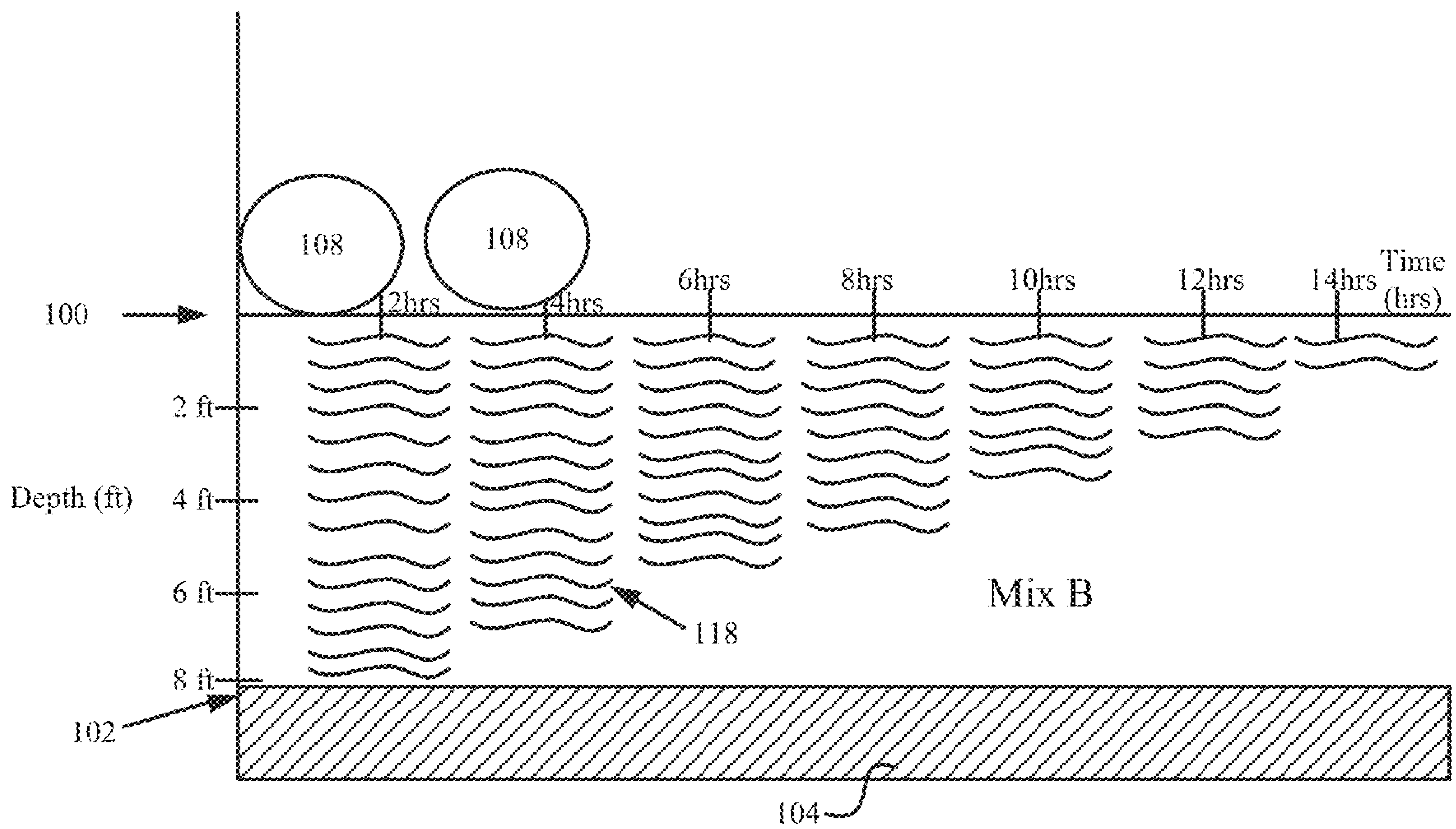

108
108
2hrs
4hrs
6hrs
8hrs
10hrs
12hrs
14hrs
Time
(hrs)
100
2 ft
Depth (ft)
4 ft
6 ft
8 ft
118
Mix B
102
104

FIG. 3

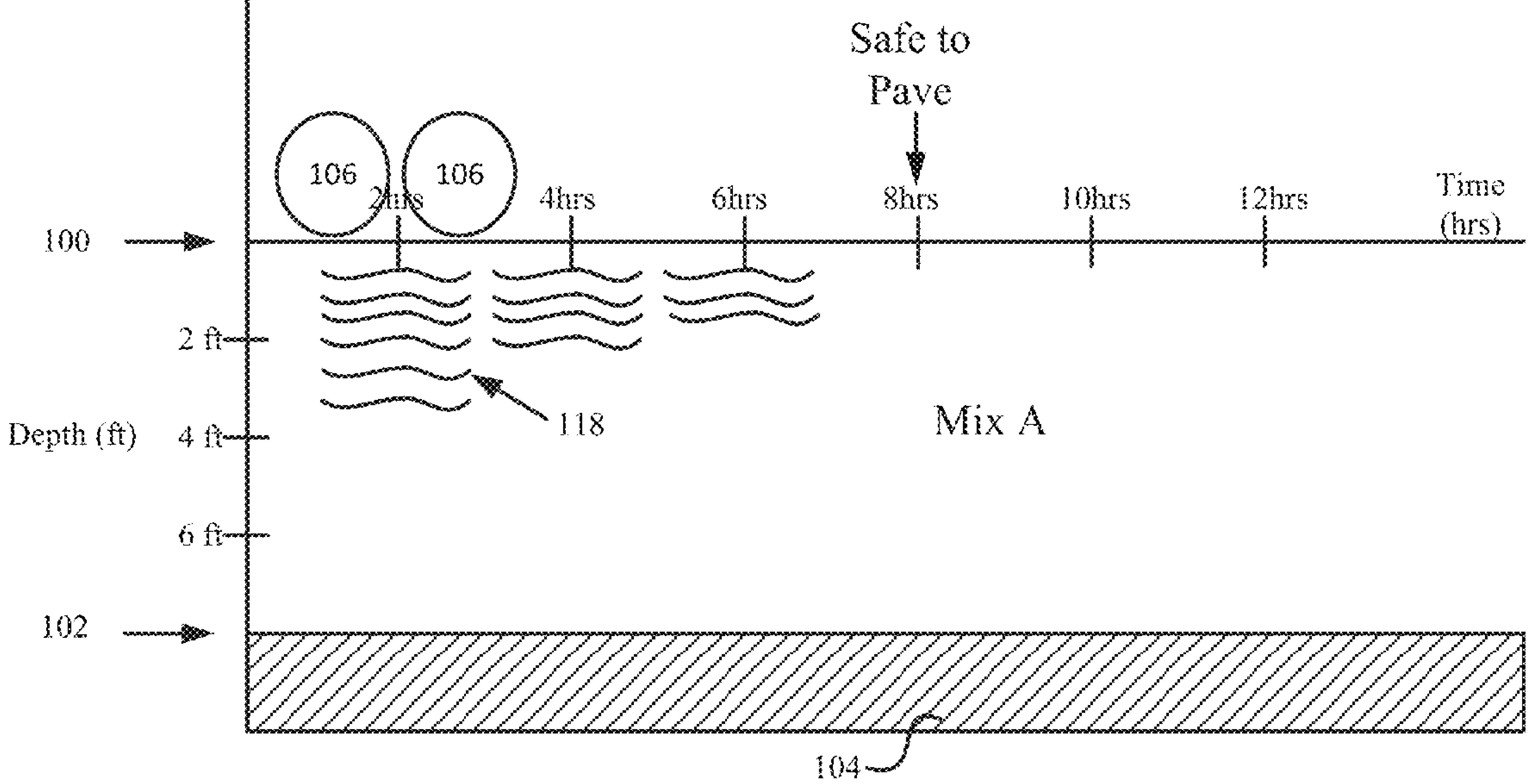

Safe to
Pave
106
106
2hrs
4hrs
6hrs
8hrs
10hrs
12hrs
Time
(hrs)
100
2 ft
Depth (ft)
4 ft
6 ft
118
Mix A
102
104

FIG. 4

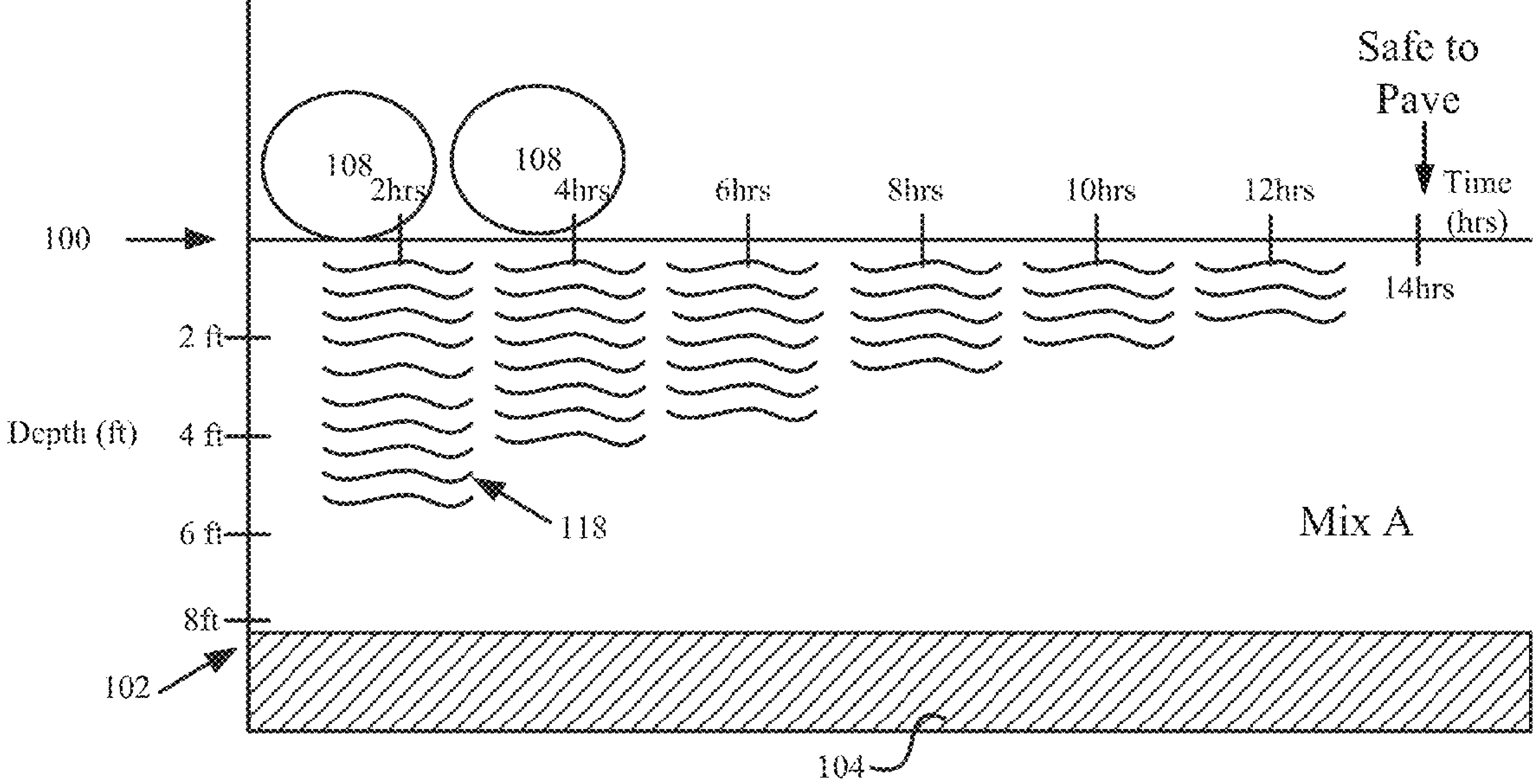

Safe to
Pave
108
108
2hrs
4hrs
6hrs
8hrs
10hrs
12hrs
Time
(hrs)
14hrs
100
2 ft
Depth (ft)
4 ft
6 ft
8ft
118
Mix A
102
104

FIG. 5

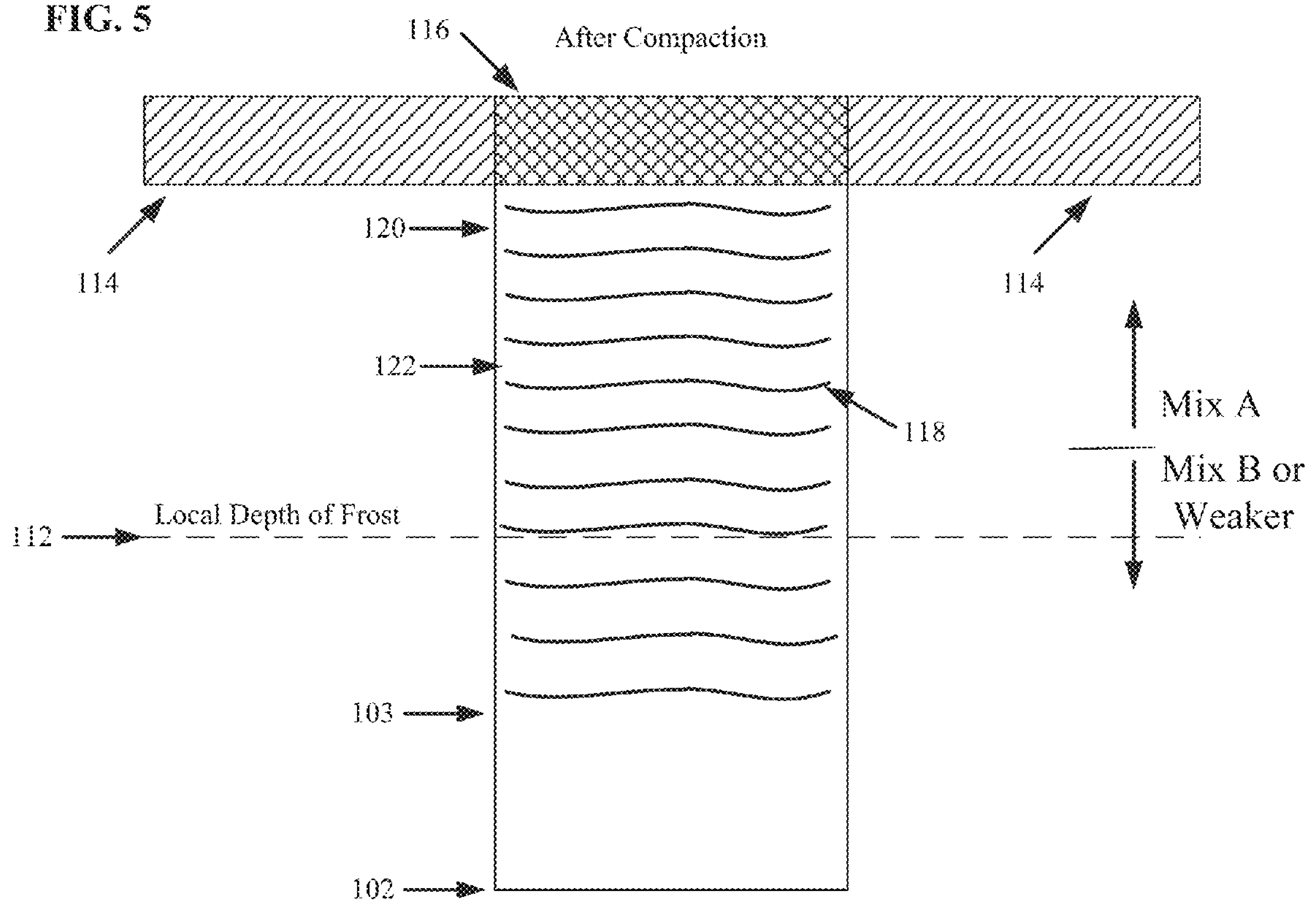

116
After Compaction
114
120
114
122
Mix A
118
Mix B or
Weaker
112
Local Depth of Frost
103
102

FIG. 6

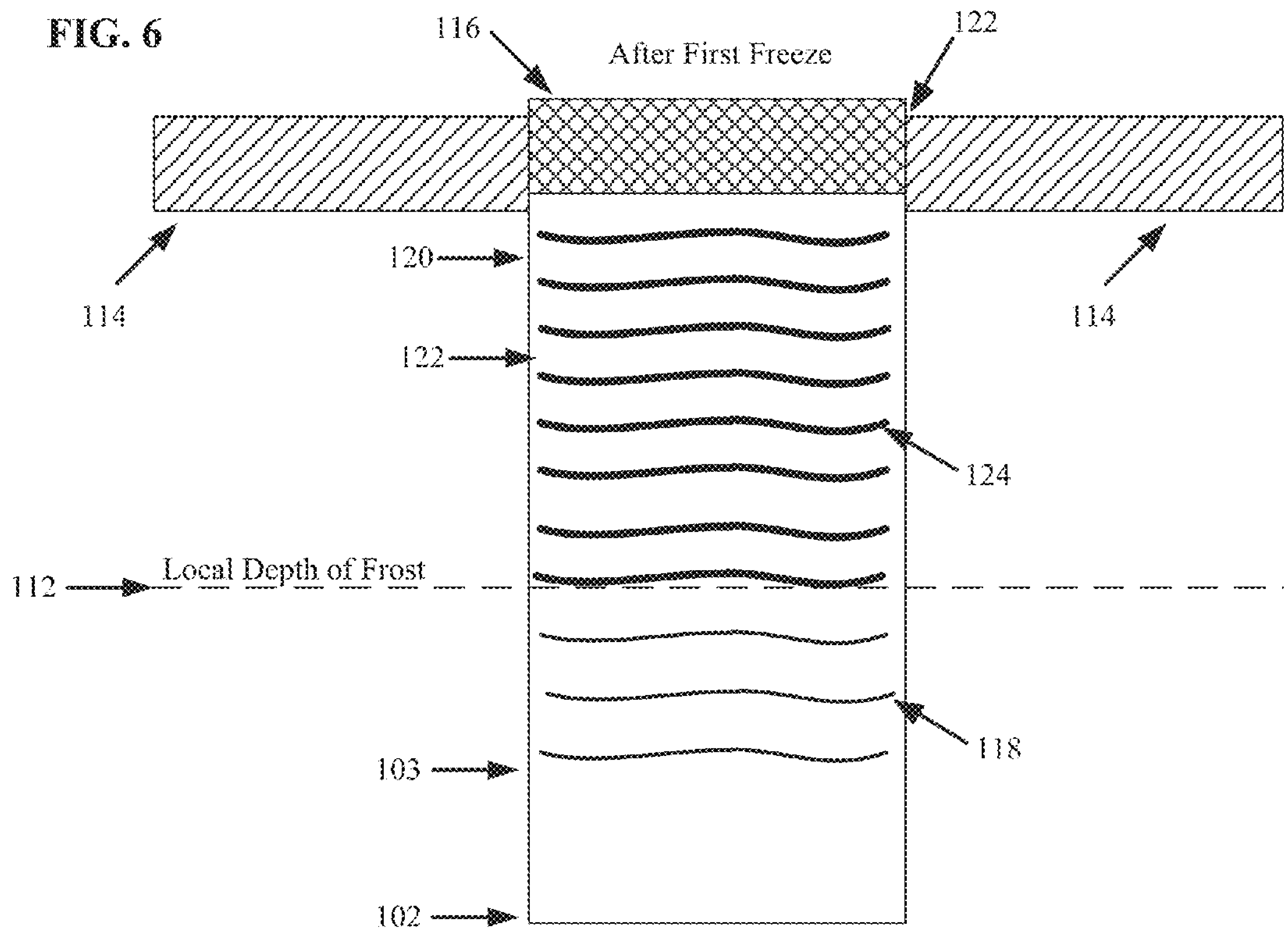
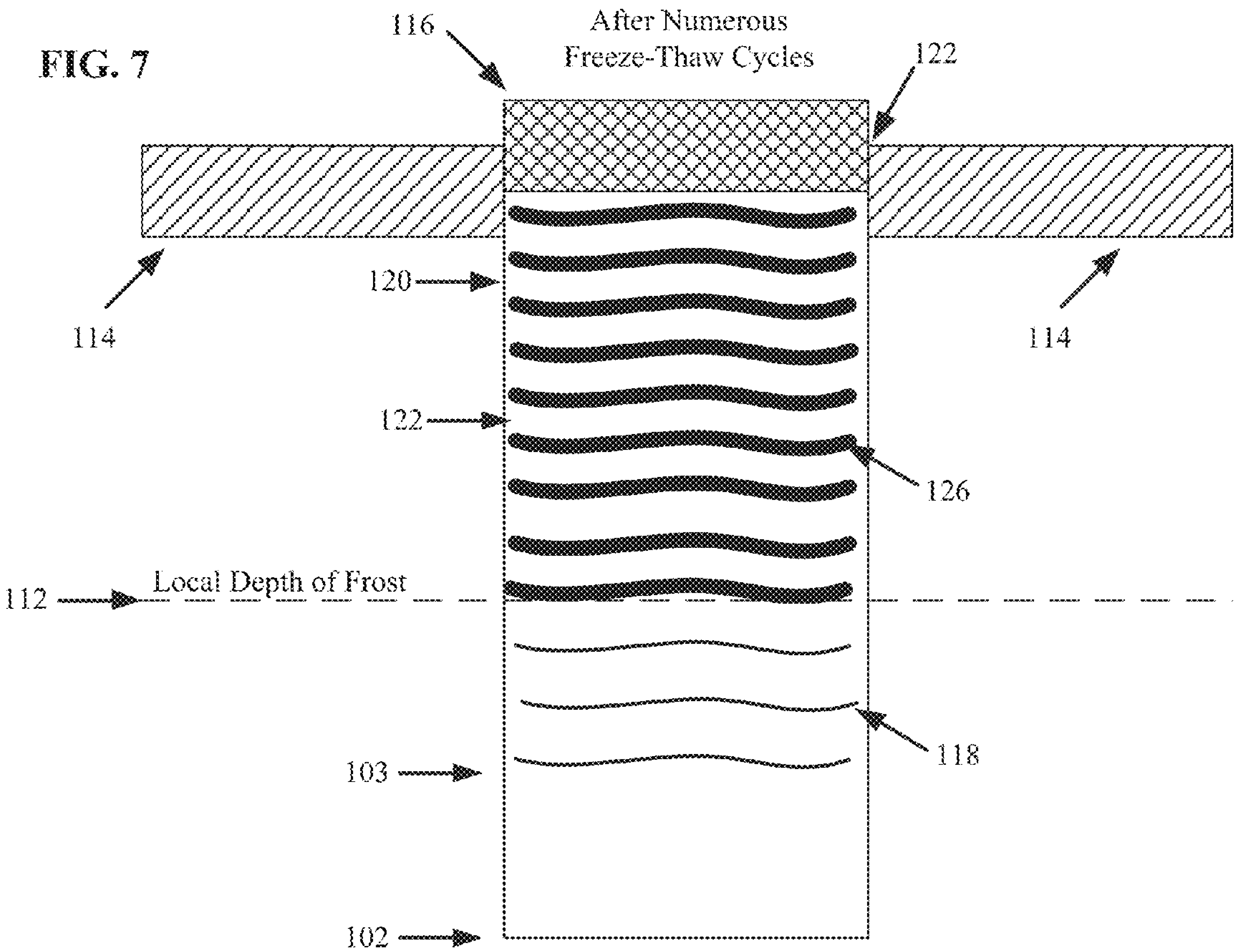
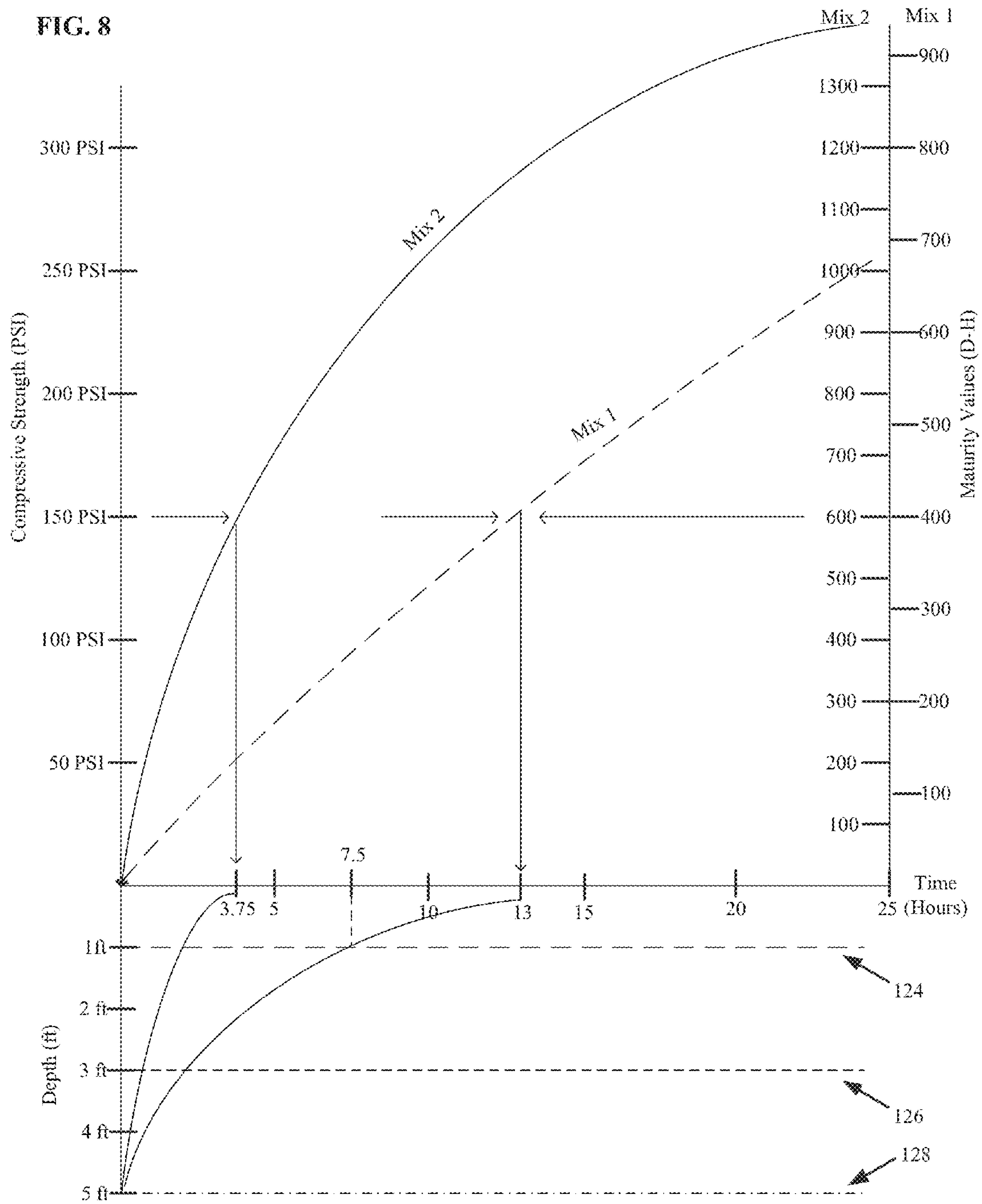

116
After First Freeze
122
114
120
114
122
124
112
Local Depth of Frost
118
103
102

FIG. 7



After Numerous
Freeze-Thaw Cycles
116
122
114
120
114
122
126
112
Local Depth of Frost
118
103
102

FIG. 8



Mix 2
Mix 1
Compressive Strength (PSI)
300 PSI
250 PSI
200 PSI
150 PSI
100 PSI
50 PSI
Maturity Values (D-H)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
900
800
700
600
500
400
300
200
100
Mix 2
Mix 1
7.5
3.75
5
10
13
15
20
25 (Hours)
Time
Depth (ft)
1ft
2 ft
3 ft
4 ft
5 ft
124
126
128

FIG. 9

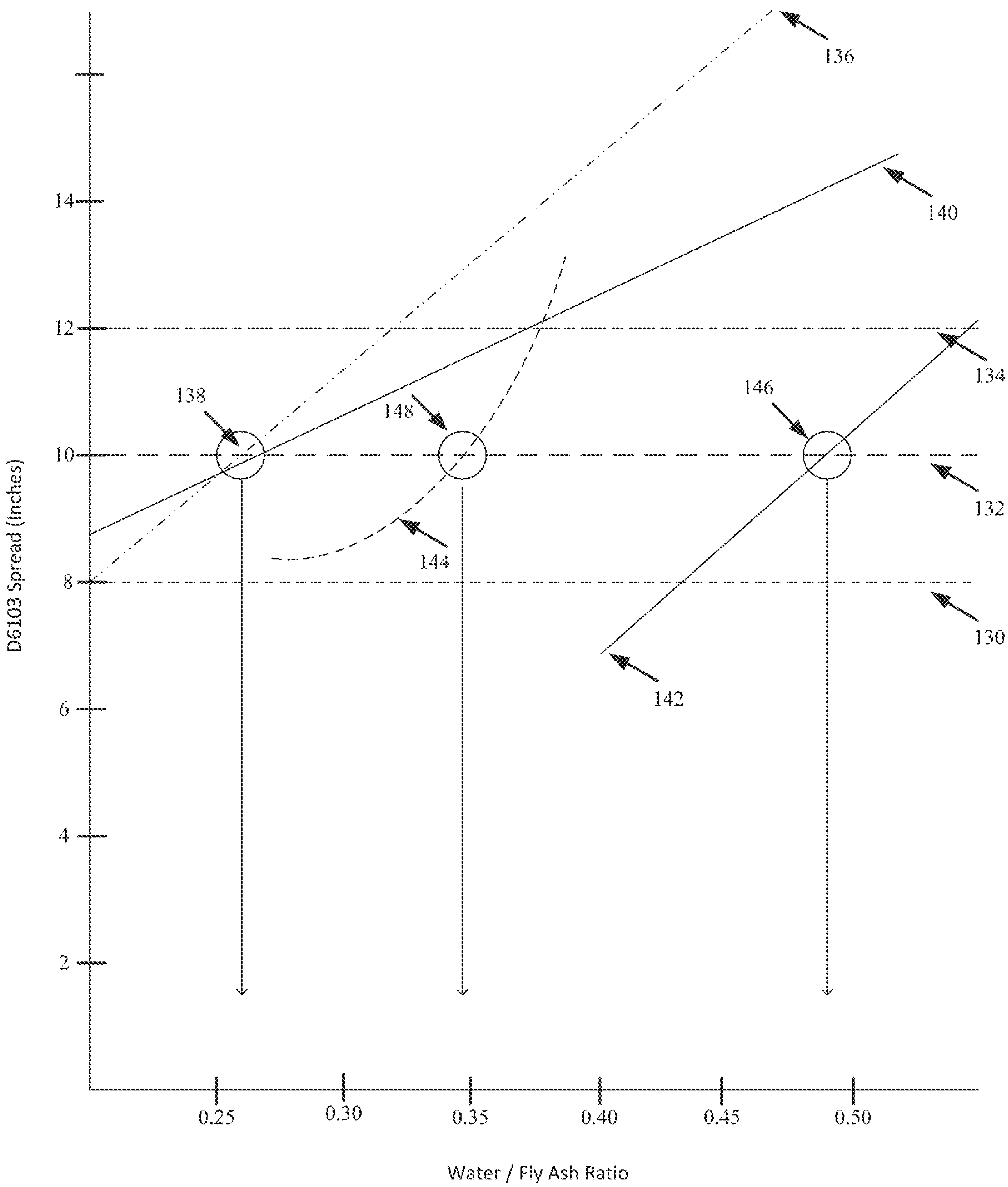

136
140
134
132
130
138
148
146
144
142
14
12
10
8
6
4
2
D6103 Spread (Inches)
0.25
0.30
0.35
0.40
0.45
0.50
Water / Fly Ash Ratio

FIG. 10

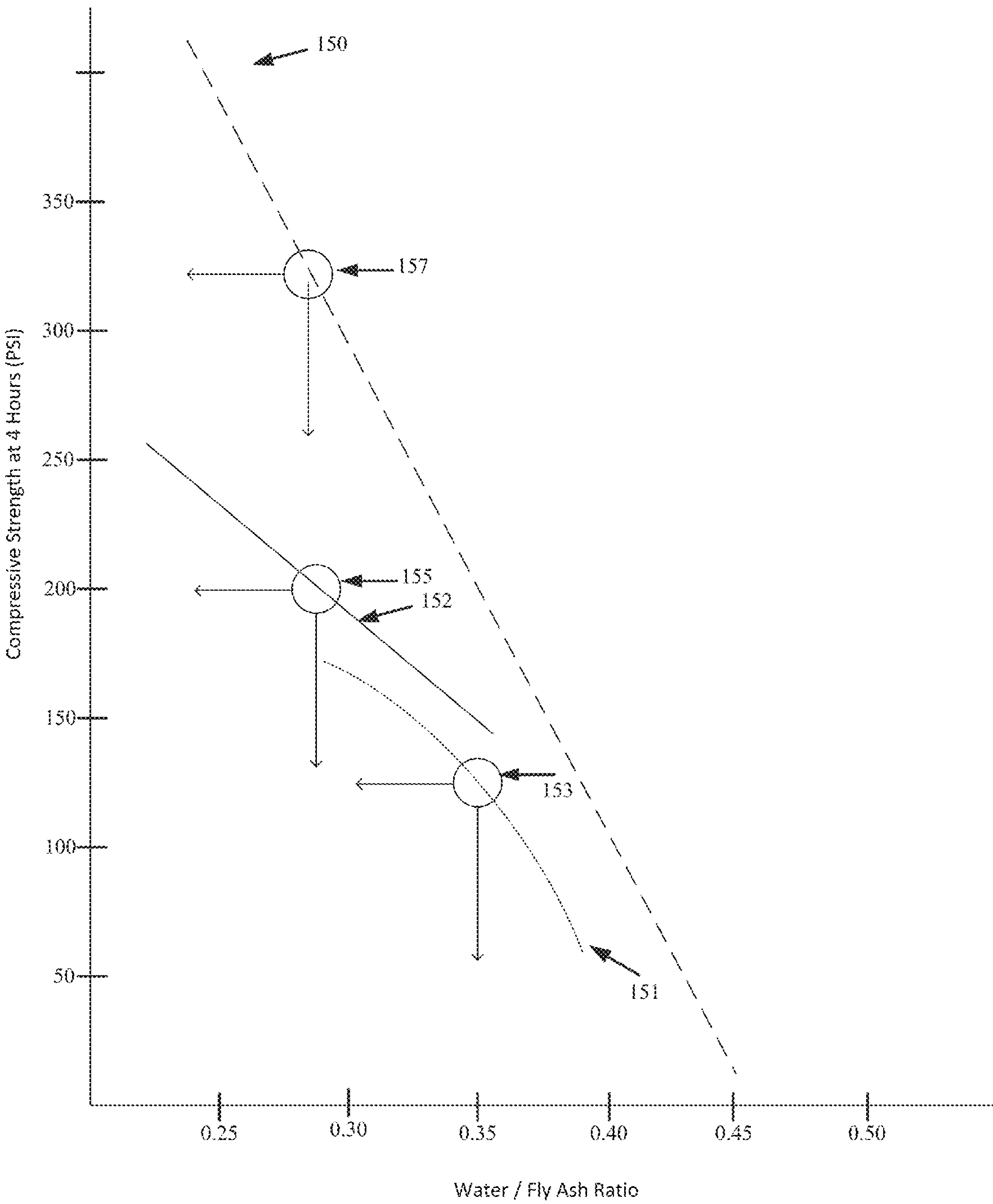

150
157
155
152
153
151
350
300
250
200
150
100
50
Compressive Strength at 4 Hours (PSI)
0.25
0.30
0.35
0.40
0.45
0.50
Water / Fly Ash Ratio

FIG. 11

Gentleman C Ash: 0.28 at 10 Inch Spread

Valmont C Ash: 0.49 at 10 Inch Spread

Ratio	Gentleman	Valmont	Estimated Water/Fly Ash	Estimated Strength
1:0	100%	0%	0.28	320 PSI
2:1	67%	33%	0.35	200 PSI
1:1	50%	50%	0.39	120 PSI
1:2	33%	67%	0.42	60 PSI
1:3	25%	75%	0.44	20 PSI

FIG. 12

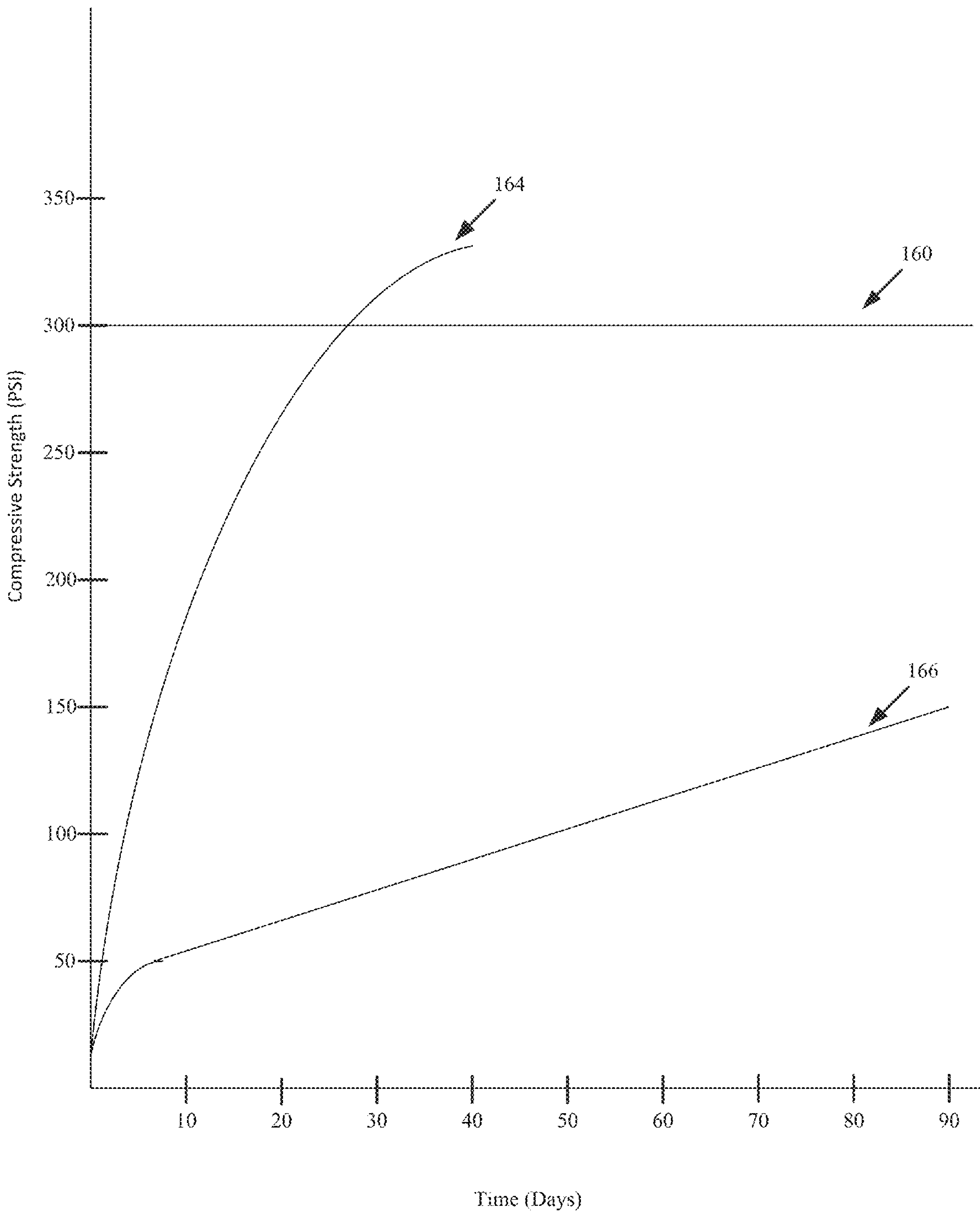

164
160
166
350
300
250
200
150
100
50
Compressive Strength (PSI)
10
20
30
40
50
60
70
80
90
Time (Days)

FIG. 13

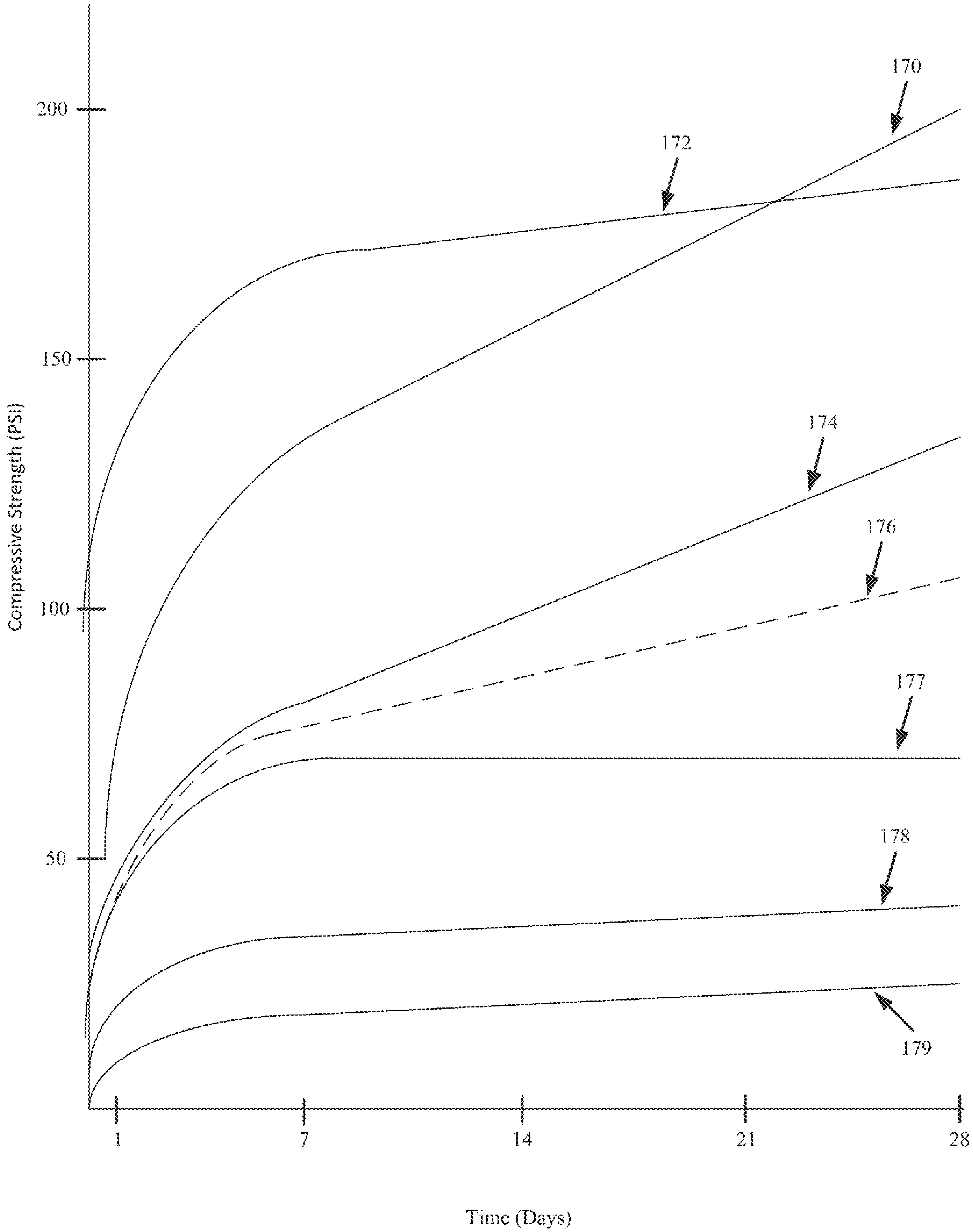

Compressive Strength (PSI)
200
150
100
50
170
172
174
176
177
178
179
1
7
14
21
28
Time (Days)

FIG. 14

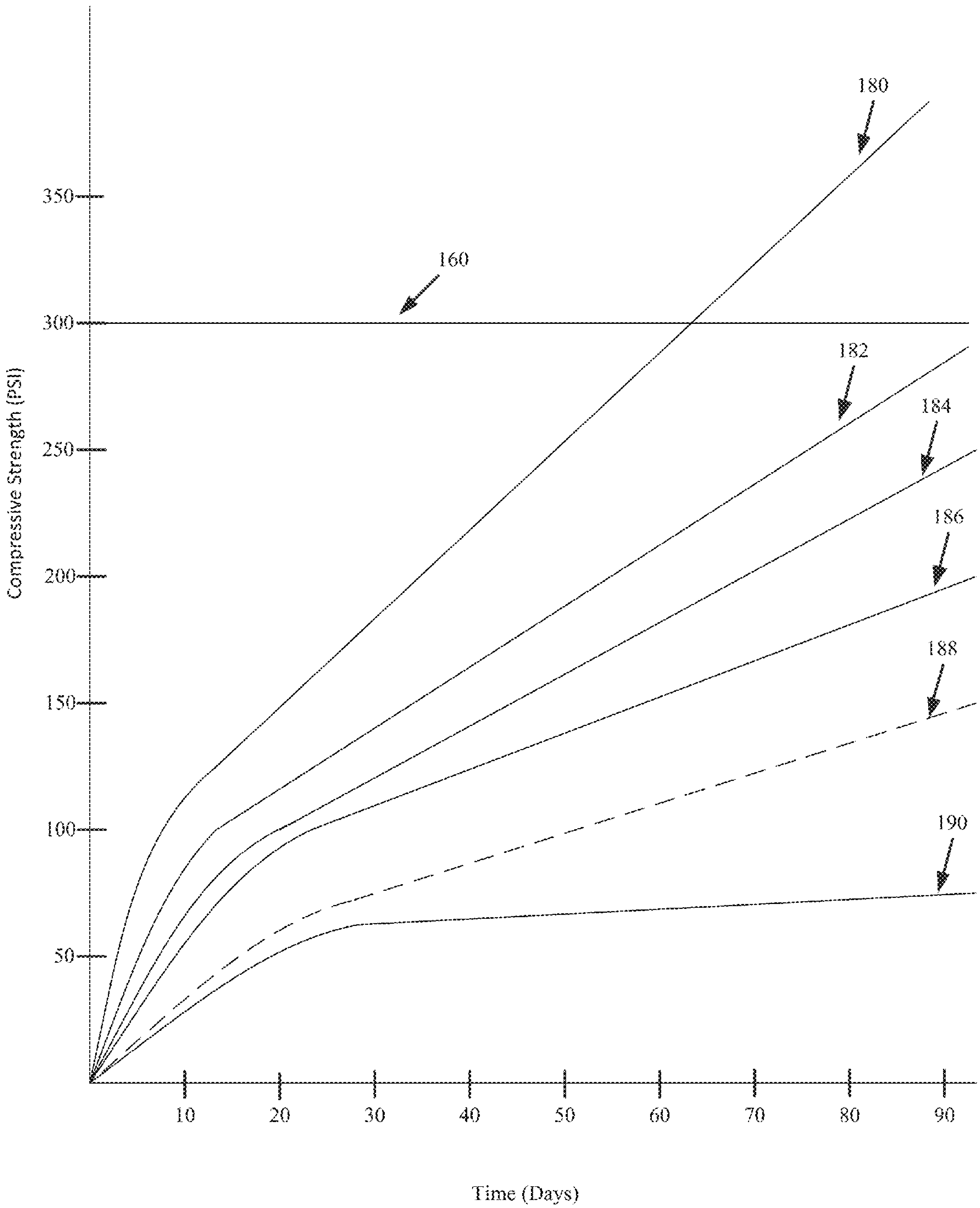

180
160
182
184
186
188
190
350
300
250
200
150
100
50
Compressive Strength (PSI)
10
20
30
40
50
60
70
80
90
Time (Days)

FIG. 15

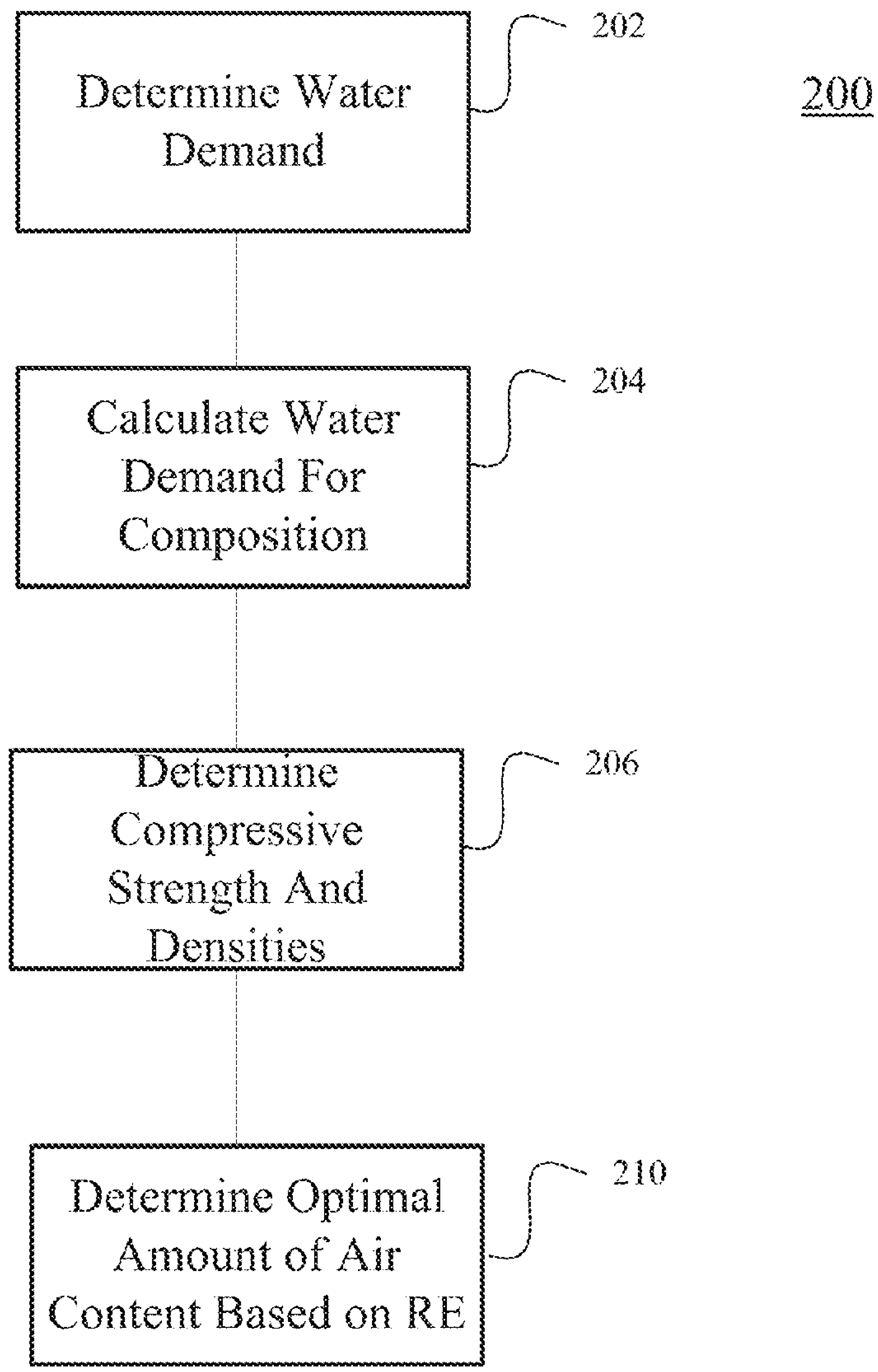

Determine Water Demand
202
200
Calculate Water Demand For Composition
204
Determine Compressive Strength And Densities
206
Determine Optimal Amount of Air Content Based on RE
210

FIG. 16

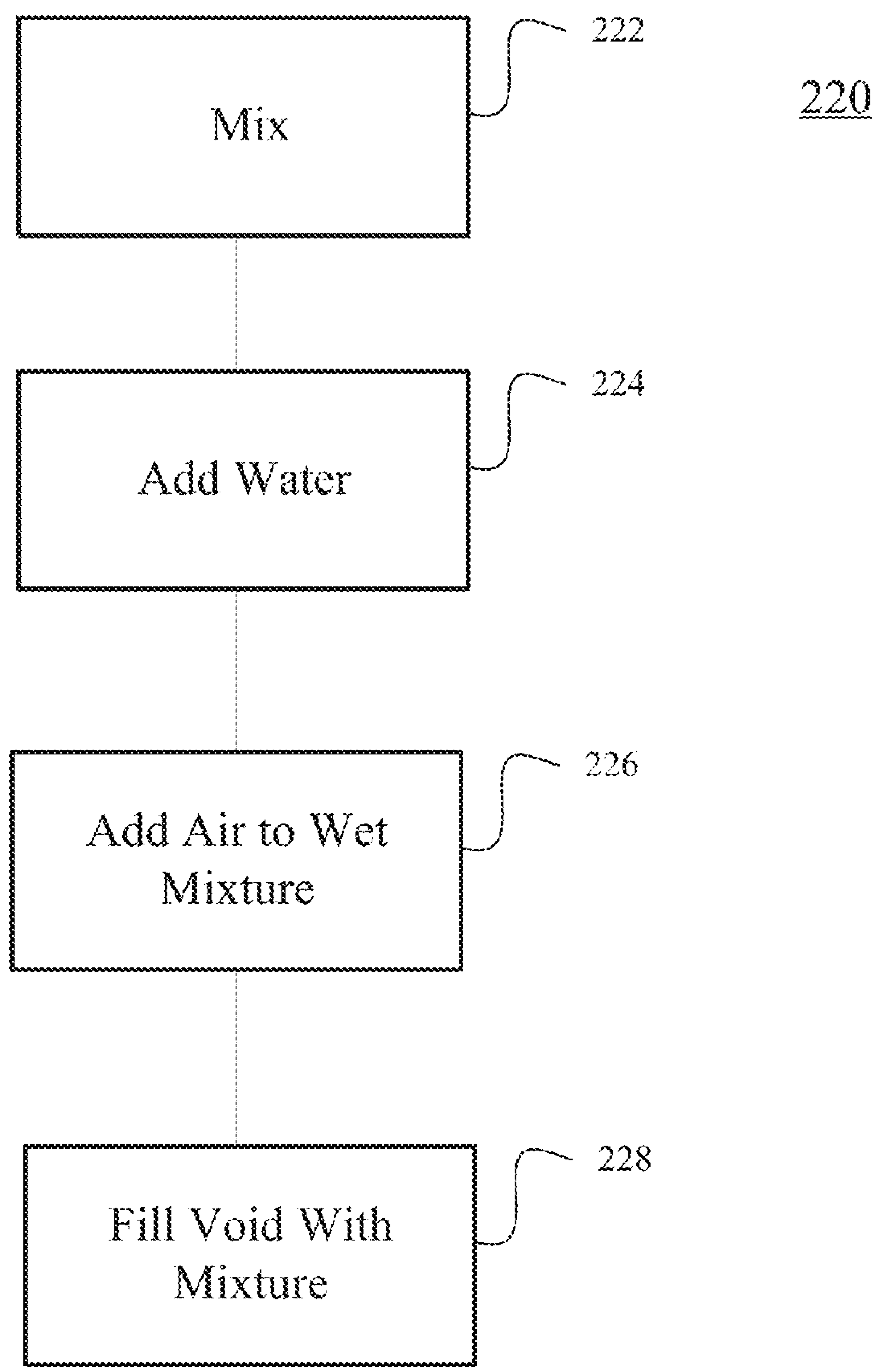

222
220
Mix
224
Add Water
226
Add Air to Wet Mixture
228
Fill Void With Mixture

FIG. 17

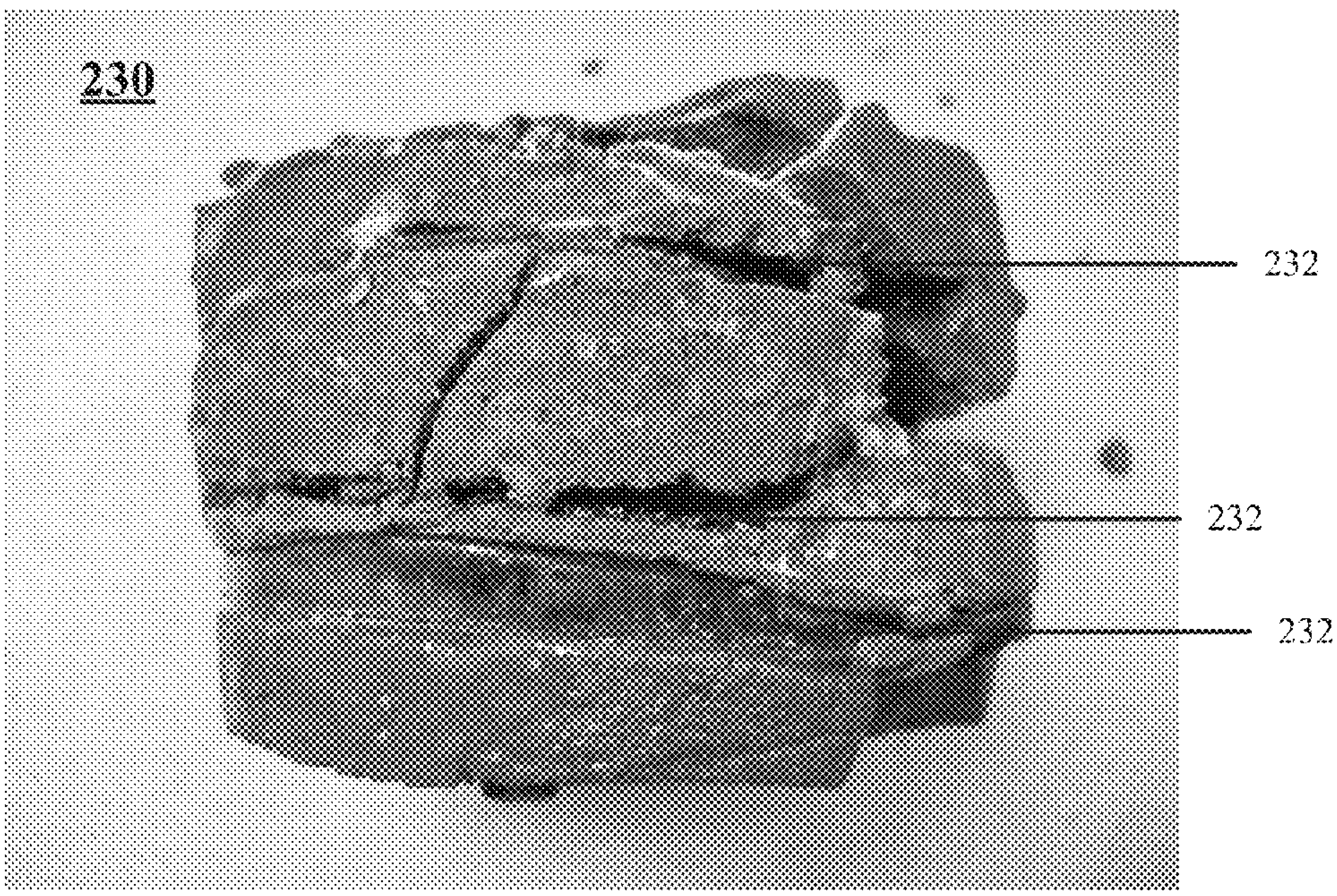
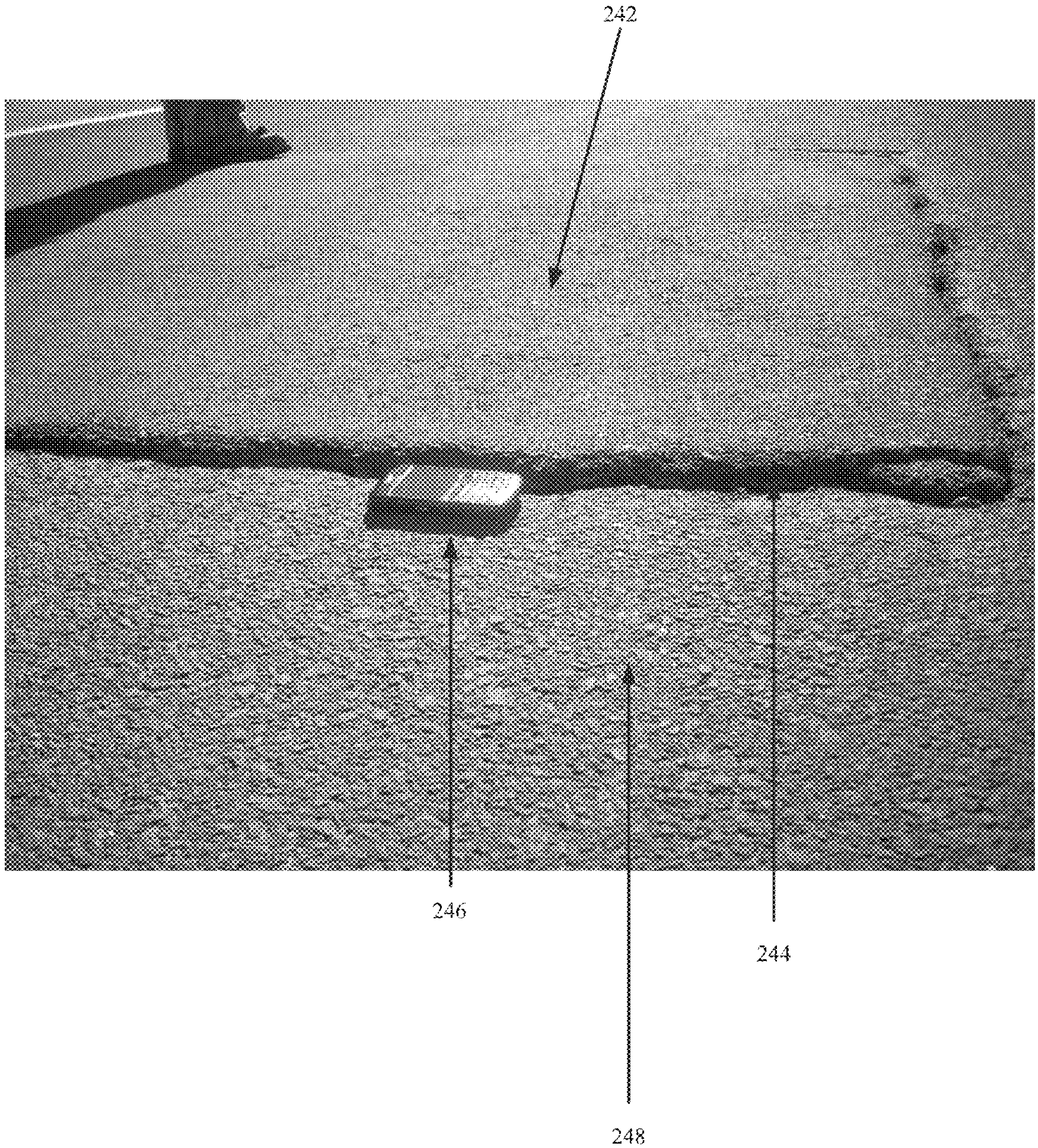


FIG. 18



FOAMED COMPOSITIONS FOR REDUCING FREEZE-THAW HEAVE RISK, AND METHODS OF UTILIZING AND PRODUCING THE SAME

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Ser. No. 61/395,956, filed on May 20, 2010, U.S. Provisional Patent Application Ser. No. 61/395,930, filed on May 20, 2010, and U.S. Provisional Patent Application No. 61/455,604, filed on Oct. 25, 2010.

INTRODUCTION

Generally, to manipulate underground utilities or for equivalent reasons, an operator must excavate the area on top of and surrounding the work site to gain access to the underground area of interest. Following manipulation of the area of interest, e.g., water pipe or sink hole, the excavated area will be backfilled with a composition that promotes subsequent use of the surface as quickly as possible. For example, when the area of interest lies beneath a road surface crucial for a city's traffic pattern, the time from excavation to reopening of the road is critical. The downtime following repair is directly correlated to when the backfilled surface will support the anticipated use, i.e., vertical loads from routine traffic or compression from pavement structures which withstand substantial loads.

In addition to the downtime associated with said repair, one must also consider the longevity and integrity of the backfilled area. Often, even when downtime is minimized using specific compositions, the same compositions are subject to facture cracking during compaction of the asphalt allowing subsequent ice lens formation during freeze thaw cycles. The ice lens formation within the backfill drives the backfill—and surface pavement covering said backfill—up as the ice lenses freeze and expand. This results in an uneven surface and the need for further repair to the backfilled site. The resulting uneven surface also damages the shovels of city snowplows and causes general damage to vehicles subjected to the uneven road surface.

U.S. Pat. No. 5,106,422 (the "'422 patent") discloses a backfill composition including a minor amount of cementitious Class C fly ash and other filler materials in a major amount. When such materials are combined with water, they produce a backfilling material. The backfilling composition of the '422 patent ranges in amount from about 2 to 10 parts by weight filler material to about 1 part by weight Class C fly ash with sufficient water to react with both Class C fly ash and filler material. Problems have been encountered with the formulations of the '422 patent, and new compositions are necessary to solve these problems.

For example, freeze-thaw vertical heave of pavement patches is a common issue with current '442 patent backfill compositions. Several investigations in regions having freeze-thaw temperature zones have discovered the freeze-thaw vertical heave of pavement patches is due to the formation of ice lenses in the horizontal cracks of current backfill compositions. The creation of these horizontal cracks results from the compacting of asphalt patches overlying the backfilled void and/or post placement excavating and patch installation. The compacting of asphalt patches is necessary to achieve the correct density.

Most agencies require the type of pavement repair material be the same type and thickness as the original pavement, to achieve compatibility with the trench repair. In some cases, agencies also require a T-patch where the surface area of the patch is larger than the trench backfill surface area. Some installers and municipalities have stopped using compositions of the '422 patent because of frost heave problems. Most roadways are constructed of asphalt paving materials; hence most trenches are repaired with asphalt paving materials. To achieve long-term durability of the trench patch, the asphalt must be similarly compacted to normal specifications (often to 92% to 96% of the theoretical maximum density). To achieve these densities, most contractors utilize their steel-wheeled compactors in vibratory mode, not static-mode.

However, typically, the strength of the backfill material near the surface is not sufficiently strong enough to resist the horizontal shear stresses caused by the compactive mechanism, e.g., rollers, resulting in horizontal compaction fractures.

When water infiltrates these horizontal cracks and freezes in cold weather climates, the entrapped water expands vertically by around 11% of its volume/thickness. Thawing allows more water to infiltrate the new crack volume, which then expands around 11% during the next freezing cycle. Repeated freeze-thaw cycles during a winter can create individual ice lenses up to ⅜ of an inch or more. The heave of the pavement patch at the surface is the sum of the thickness of these ice lenses formed above the local frost depth, and can be up to 3-inches above the original pavement surface or more.

The compositions and methods of the present disclosure alleviate the encountered problems. Namely, the present disclosure alleviates the frost-heave typically associated with previous backfill and reduces ice lens formation. The compositions and methods of the present disclosure also provide a more homogenous mixture, e.g., the high air content contributes to fluidity and reduces gravity segregation; thereby preventing the flotation of carbon particles to the surface and resulting in weakened planes for early freezing or compactive cracking.

The compositions and methods of the present disclosure also provide a composition with a lower modulus of elasticity that is more forgiving & less-brittle during compaction; thereby decreasing the likelihood of horizontal crack development.

In addition, the present disclosure identifies methods for determining and using compositions that reach a critical compression strength quicker, maintain a lower removability modulus ("RE"), prevent water from becoming trapped within the backfilled composition, expedite backfill mixture optimization, and provide more predictable and repeatable laboratory procedures, mix designs and testing methods.

The present disclosure further provides a composition that reduces the backfill composition setting time; thereby reducing the time to pave or patch and resulting in a total reduction in time from the start of backfilling to a return to normal use.

Foamed Backfill Compositions for Reducing Freeze-Thaw Heave Risk, and Methods of Utilizing and Producing the Same

The present disclosure reveals a high-performance backfill composition, generating higher early strengths yet still sufficiently low ultimate strengths, at the same time improving freeze-thaw durability and reducing the occurrence of frost-heaved trench patches. In an embodiment, the present disclosure achieves these goals by purposely including air content for a new and improved cementitious fly ash composition for backfilling voids. In an embodiment, the amount of air content created by varying cellular foam additions can be optimized for the ultimate strength gain desired, the performance of specific fly ashes used, and the ambient temperature during the backfilling process.

The compositions and methods of the present disclosure generally solve problems with frost-heave in backfilled voids resulting, mostly, from ice lens formation. Compositions and methods of the present disclosure prevent problematic compaction fractures, which allow frost-heave, by determining the strength needed to resist compaction fractures to depths of local frost penetration. Once this strength level is determined for specific equipment & procedures, various compositions can be utilized to achieve this strength level in time frames desired to patch and open the roadway to traffic. Different strength levels can be used below the depth of frost-penetration and/or influence of compaction equipment, thus optimizing the overall economics of trench backfill, subject to the desired time constraints.

Interestingly, testing shows that time to set is a function of the free lime concentration in a the blend of cementitious and non-cementitious fly ashes or other fillers, and the water/fly ash ratio, but essentially independent of the amount of air content, e.g., from cellular foam. Hence a faster set time can be achieved with more blends using more cementitious fly ash and lower water/fly ash ratios, while the ultimate strength can be limited with higher amounts of air content.

In an embodiment, a composition of the present disclosure includes a composition for preventing ice lens formation comprising from 5% to 70% air; from 5% to 90% cementitious fly ash; and from 5% to 70% water, wherein the composition has a compressive strength of between 10 and 60 PSI after 4 hours and a removability modulus of less than 1.8 after 28 days. Additional compositions can include a filler from 5% to 80%. Unless otherwise stated, all percentages of compositions are weight percent based on the final weight of the composition including the weight of water and air. The exception is that all percentages of air are based on volume of the final composition as defined in the Detailed Description.

In an embodiment, a method of the present disclosure includes a method of determining a composition to prevent ice lens formation comprising determining the water demand of each fly ash within the composition to achieve a desired fluidity; calculating the water demand for a combination of fly ashes; determining the compressive strength for the combination of fly ashes; and determining the amount of air content necessary for the composition to have a compressive strength of between 10 and 60 PSI after 4 hours and a removability modulus of less than 1.8 after 28 days.

An alternative method of the present disclosure comprises a method of backfilling a void to prevent ice lens formation comprising mixing cementitious fly ash and filler to a predetermined ratio; adding water to the mix of cementitious fly ash and filler to make a wet mixture; adding air to the wet mixture, wherein the predetermined mix of cementitious fly ash and filler, the addition of water and the addition of air makes a composition having a compressive strength of between 10 and 60 PSI within 4 hours and a removability modulus of less than 1.8 after 28 days; and adding the composition to a void.

While the disclosure will be described with respect to preferred embodiment configurations and with respect to particular compositions or methods used therein, it will be understood that the disclosure is not to be construed as limited in any manner by either such configuration or components described herein. Also, while the particular types of equipment, compositions and uses are described herein, it will be understood that such particular compositions, equipment or uses are not to be construed in a limiting manner. Instead, the functionality of those compositions and methods should be appreciated. These and other variations of the disclosure will become apparent to those skilled in the art upon a more detailed description of the disclosure.

The advantages and features which characterize the disclosure are pointed out with particularity in the claims annexed hereto and forming a part hereof. For a better understanding of the disclosure, however, reference should be had to the drawing which forms a part hereof and to the accompanying descriptive matter, in which there is illustrated and described an embodiment of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to the drawing, wherein like numerals represent like parts throughout the several views.

FIG. **1** illustrates the creation of horizontal cracks by a small compactor on a backfilled trench as a function of time.

FIG. **2** illustrates the creation of horizontal cracks by a large compactor on a backfilled trench as a function of time.

FIG. **3** illustrates the creation of horizontal cracks by the same small compactor as FIG. **1** but with a new backfill composition (Mix A) that develops strength faster than the backfill composition used in FIG. **1** (Mix B).

FIG. **4** illustrates the creation of horizontal cracks by the same large compactor as FIG. **2** but with a new backfill composition (Mix A) that develops strength faster than the backfill composition used in FIG. **2** (Mix B).

FIG. **5** is a close up view of the horizontal fractures discussed in FIGS. **1** through **4**.

FIG. **6** illustrates the same horizontal fractures of FIG. **5** after saturation with infiltrating water and the first freeze cycle.

FIG. **7** illustrates the horizontal fractures of FIG. **5** after several cycles of saturation with infiltrating water followed by freeze thaw cycles.

FIG. **8** illustrates the hypothetical strength development curves of two different backfill compositions based on both compressive strength (PSI) and the maturity method (degree-hours), as well as the depth of fracturing of each mix with the same compactor as function of starting time.

FIG. **9** illustrates the results of testing different fly ashes at different water to fly ash (W/FA) ratios to determine the resulting fluidity, i.e., spread for each fly ash.

FIG. **10** illustrates the 28 day compressive strengths of various cementitious fly ashes, e.g., Class C fly ash, as a function of the water to fly ash ratio (W/FA) with desired fluidity identified by each circle.

FIG. **11** illustrates how using the previously tested water demand for several fly ashes, including cementitious and non-cementitious fly ashes, can help develop the correct ratios and water content for a desired strength.

FIG. **12** illustrates strength versus time curve of compositions from the ’422 patent.

FIG. **13** illustrates strength versus time curves of various compositions from the present disclosure in relation to a composition from the ’422 patent.

FIG. **14** illustrates hypothetical strength versus time curves of various compositions from the present disclosure in relation to a composition from the ’422 patent.

FIG. **15** illustrates an embodiment of the steps for determining an optimum composition to meet a specified setting time and removability modulus.

FIG. **16** illustrates an embodiment of the steps for backfilling a void with a composition of the present disclosure.

FIG. **17** is an ice lens formation in a composition as suggested by the ’422 patent.

FIG. **18** is a pavement patch that has suffered frost heave due to the formation of ice lenses.

DETAILED DESCRIPTION

The present disclosure provides compositions and methods for reducing freeze-thaw heave risk over flowable-filled voids; and, more particularly, to a composition for reducing horizontal cracks and the subsequent formation of ice lenses, and methods of producing and utilizing the same.

Generally, one must consider several factors when determining an appropriate composition for backfilling a trench or void in the middle of a public roadway or street. These factors include the flowability or spread of the backfill, the setting time of the backfill, the air content of the backfill, the final compressive strength of the backfill and the removability of the backfill.

For example, strength development in backfilling compositions is directly related to the amount of cementitious material and water content. In an embodiment of this disclosure, the primary cementitious material is cementitious fly ash. Water content of the composition also influences strength development as the addition of water controls flowability or slump. While it is desirable to support the intended use, e.g., traffic loading, the final strength of the composition must still allow later excavation. In certain embodiments, a composition should be less than 300 psi for ease of later excavation.

In addition, considering the flowability of the compositions will assume the advantage of the self-compacting and self-leveling qualities of composition. In some embodiments of the present disclosure, the flowability may be determined using ASTM D6103, e.g., utilizing a moistened 3 inch diameter by 6 inch high open-ended cylinder filled with a composition. Along with strength development and flowability, setting time is an additional factor to consider when determining a suitable composition. The faster the composition sets and gains strength after filling the void, the sooner the backfilled surface may be paved or patched and returned to normal use.

The present disclosure reveals a high-performance backfill composition, generating higher early strengths yet still sufficiently low ultimate strengths, at the same time improving freeze-thaw durability and reducing the occurrence frost-heaved trench patches. In an embodiment, the present disclosure achieves these goals using increased air content for a new and improved cementitious fly ash composition for backfilling voids. In an embodiment, the amount of air content created by varying foam additions can be optimized for the strength gain desired, the performance of specific fly ashes used, and the ambient temperature during the backfilling process.

An embodiment of the present invention includes a composition for preventing ice lens formation comprising between 5% and 60% air; between 5% and 90% cementitious fly ash; and between 5% and 70% water, wherein the composition has a time to set of less than 40 minutes, a compressive strength of between 10 and 60 PSI after 4 hours and a removability modulus of less than 1.8 after 28 days. In additional embodiments, a composition of the present disclosure may contain a filler.

The air content of the compositions of the present disclosure will vary depending on the desired properties of the composition. For example, the amount of air within the composition helps control the final strength of the backfill. Therefore, a faster set time can be achieved with blends using more cementitious fly ash and lower water/fly ash ratios, while the ultimate strength can be limited with higher amounts of air content.

In some embodiments, the air content may be determined by the following formula using wet densities before and after the addition of air:

$$\text{Air content} = \frac{(\text{Unit Weigh}_{no\ air} - \text{Unit Weight}_{air}) \times 100\%}{\text{Unit Weight}_{no\ air}}$$

In other embodiments, the air content can be determined using ASTM C231.

In certain embodiments, the air content is achieved by mixing an air entraining agent, i.e., a dry surfactant or liquid admixture into the cementitious fly ash and/or filler prior to addition of water. In these embodiments, the air content may by uniformly distributed by mixing directly in a truck or by mixing in a commonly used agitation/mixing device. The mixing process can occur with prior to addition of water, after addition of water or simultaneously with the addition of water.

In another embodiment, the air content is achieved by addition of an air entraining agent after mixture of the dry ingredients (cementitious fly ash and possible filler) with water but prior to applying the composition to the void.

In specific embodiments, the air content may be achieved by adding a pre-formed cellular foam, e.g., GEOFOAM SNP foam liquid concentrate available from Cellular Concrete, LLC., 7020 Snowdrift Road, Suite 102, Allentown, Pa. 18106 or 5916 McIntyre St, Golden, Colo. 80403. The cellular foam may be pervious or non-pervious, and pre-foamed thereby reducing or alleviating the need to vigorously agitate the composition to activate the air entraining agent. Any suitable foaming agent may be used that achieves the desired end properties as described herein, e.g., an anionic foaming agent, a cationic foaming agent or a non-ionic foaming agent. An example of a pervious foam is GEOFOAM SP. An example of a non-pervious foam is GEOFOAM SNP. When water penetration is not desired, a non-pervious cellular foam is preferred. Suitable cellular foam is available from a variety of sources, e.g., Cellular Concrete, LLC; Provoton Foam Concrete, 28 East Larkspur Lane, Bristol, Ill. 60512; Allied Foam Tech Corp., 146 Keystone Dr. Montgomeryville, Pa. 18936; and Vermillion LLC and Associates, 2176 Sargent Daly Dr., Chattanooga, Tenn. 37421. The choice of an appropriate cellular foam is within one of skill in the art and may be dictated by cost, environmental concerns, or the need to meet the requirements of local or national agencies. In some embodiments, the foaming agent will conform to ASTM C869 and C796, in other embodiments the air entraining agent conforms to ASTM C260.

In some embodiments, the addition of cellular foam or similar air entraining agent may occur after the addition of water to the cementitious fly ash and/or filler immediately prior to the cementitious mixture leaving a mixing truck, as the cementitious mixture leaves the mixing truck (simultaneously) or after the cementitious mixture leaves the mixing truck.

The amount of air entraining agent necessary for a given composition will vary with the desired air content, e.g., the desired final compressive strength. In some embodiments, the final air content of the composition will be between about 10% and about 75%, between about 11% and about 65%, between about 12% and about 60%, between about 13% and about 55%, between about 14% and about 50%, between about 15% and about 45%, between about 16% and about 40%, between about 17% and about 35%, between about 18% and about 30%, between about 19% and 25%, between about 15% and about 25%, between about 15% and about 30%, or between about 50% and about 70%.

In alternative embodiments, the final air content of the composition will be between about 10% and about 30%, between about 11% and about 26%, between about 12% and about 22%, between about 13% and about 20%, between about 20% and about 30% or between about 14% and 19%.

In some embodiments, the final air content will be greater than 10%, greater than 12%, greater than 14%, greater than 16%, greater than 18%, greater than 20%, greater than 22%, greater than 24%, greater than 26%, greater than 28%, greater than 30%, greater than 35%, greater than 40%, greater than 50%, or greater than about 60% final air content.

In other embodiments, the final air content of the composition will be less than 40%, less than 35%, less than 30%, less than 28%, less than 26%, less than 24%, less, than 22%, less than 20%, less than 18%, less than 16%, or less than 14%.

Fly ash can be referred to as either cementitious or pozzolanic. A cementitious material is one that hardens when mixed with water. A pozzolanic material will also harden with water but only after activation with an alkaline substance such as lime.

Two major classes of fly ash are specified in ASTM C618 on the basis of their chemical composition resulting from the type of coal burned; these are designated Class F and Class C. Class F is fly ash normally produced from burning anthracite or bituminous coal, and Class C is normally produced from the burning of subbituminous coal or lignite. Class C fly ash usually has cementitious properties in addition to pozzolanic properties due to free lime, whereas Class F is rarely cementitious when mixed with water alone.

Some relevant characteristics of fly ash are loss on ignition (LOI), fineness, chemical composition and uniformity. LOI is a measurement of unburned carbon (coal) remaining in the ash. High carbon levels, the type of carbon (i.e., activated), the interaction of soluble ions in fly ash, and the variability of carbon content are all factors affecting the performance of fly ashes.

Fineness of fly ash is most closely related to the operating condition of the coal crushers and the grindability of the coal itself. Fineness is generally defined as the percent by weight of the material retained on the 0.044 mm (No. 325) sieve. A coarser gradation can result in a less reactive ash and could contain higher carbon contents.

Chemical composition of fly ash relates directly to the mineral chemistry of the parent coal and any additional fuels or additives used in the combustion or post-combustion processes.

Uniformity of fly ash characteristics from shipment to shipment is another factor to consider when selecting fly ash or using fly ash. Some guidance documents used for fly ash quality assurance include ACI 229R (Controlled Low Strength Material), ASTM C311 (Sampling and Testing Fly Ash or Natural Pozzulans for Use as Mineral Admixture in Portland Cement Concrete), AASHTO M 295 and ASTM C618 (Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete), ASTM C593 (Fly Ash and Other Pozzolans for Use with Lime), ASTM D5239 (Standard Practice for Characterizing Fly Ash for Use in Soil Stabilization), and ASTM E1861 (Guide for the Use of Coal Combustion by-products in Structural Fills).

In an embodiment of the present disclosure, the cementitious fly ash is Class C fly ash as defined by ASTM C618 or the standards of a local agency. In other embodiments of the present disclosure, the cementitious fly ash can have cementitious properties without qualifying as Class C fly ash under ASTM C618 or an equivalent standard. A cementitious fly ash of the present disclosure is a fly ash that sets (e.g., solidifies to 4 psi) within about thirty minutes at a water content of 30% by weight when water and cementitious fly ash are the only ingredients. The cementitious fly ash of the present disclosure can be obtained from a variety of sources based on economics, location, chemical properties, or additional criteria. For example, cementitious fly ash can be obtained from a coal-fired power plant local to the area of eventual use. In some embodiments, the cementitious fly ash is supplemented with additional calcium carbonate, free lime or equivalent to provide cementitious properties.

In an embodiment of the present disclosure, a composition has between about 5% and about 90% cementitious fly ash, between about 15% and about 70% cementitious fly ash, between about 20% and about 60% cementitious fly ash, between about 20% cementitious fly ash and about 50% cementitious fly ash, between about 35% and about 50% cementitious fly ash, and between about 40% and about 47%.

In some embodiments of the present disclosure, a composition has less than about 80% cementitious fly ash, less than about 70% cementitious fly ash, less than about 60% cementitious fly ash, less than about 50% cementitious fly ash, less than about 40% cementitious fly ash, less than about 20% cementitious fly ash, or less than about 10% cementitious fly ash. In additional embodiments of the present disclosure, the composition has greater than about 10% cementitious fly ash, greater than about 20% cementitious fly ash, cementitious fly ash, greater than about 30% cementitious fly ash, greater than about 40% cementitious fly ash, greater than about 50% cementitious fly ash, greater than about 60% cementitious fly ash, greater than about 70% cementitious fly ash, greater than about 80% cementitious fly ash, or a greater than about 90% cementitious fly ash.

In an embodiment of the presently disclosed composition, the water is standard city potable water. In another embodiment, the water used in the composition is substantially purified of additional minerals or other impurities. In still another embodiment of the present disclosure, the water is non-potable water. In additional embodiments, the water is selected based on its natural impurities, i.e., specific mineral content like calcium, magnesium, iron, or similar water minerals.

The water content of the presently disclosed composition may vary depending on desired flowability, setting time and final compressive strength. In an embodiment, of the present disclosure, a composition has a the water content of between about 5% and about 70%, between about 15% and about 60%, between about 25% and about 50%, between about 35% and about 45%, between about 10% and about 35%, between about 25% and about 35%. In additional embodiments, a composition has greater than about 10% water, greater than about 20% water, greater than about 30% water, greater than about 40% water, greater than about 50% water or greater than about 60% water. In other embodiments, a composition has less than about 55% water, less than about 45% water, less than about 35% water, less than about 24% water, less than about 20% water, less than about 15% water, or less than about 10% water. Any water included with additional ingredients, e.g, aqueous water retarders, foaming agents, etc. under the circumstances encountered in the field by the inventors has been negligible in comparison to the primary batch water and therefore has not been included in the above calculations. Depending on the actual water content of the additional ingredients used it may be necessary to consider the additional water in the final water concentrations.

In some embodiments of the present disclosure, a composition will include at least one filler. In additional embodiments, a composition will include only one filler, while in other embodiments, a composition will contain only two fillers. In still additional embodiments, a composition will contain less than 3 fillers or less than 4 fillers. A filler in the present disclosure can be additional fly ash, e.g., type F fly ash as determined by ASTM C618 or equivalent standard. A filler can also be non-specification grade non-cementitious fly ash, e.g., a fly ash that does not meet the specifications determined by ASTM C618. In certain embodiments a filler can be sand, bottom ash, quarry fines, soil, gravel and Portland cement, aggregate, or recycled version thereof. Determination of the filler material can be based on economics, availability, city, county and/or state specifications, or on the desired properties of the composition, e.g., desired setting time, flowability, or final compressive strength.

In an embodiment, a composition of the present disclosure will have between about 5% and about 80% filler, between about 15% and about 70% filler, between about 25% and about 60% filler, between about 35% and about 50% filler. In certain embodiments, a composition of the present disclosure will have less than about 80% filler, less than about 70% filler, less than about 60% filler, less than about 50% filler, less than about 40% filler, less than about 30% filler, less than about 20% filler, or less than about 10% filler. In still other embodiments, a composition of the present disclosure will have greater than about 10% filler, greater than about 20% filler, greater than about 30% filler, greater than about 40% filler, greater than about 50% filler, greater than about 60% filler, or greater than about 70% filler.

Compositions of the present disclosure will have a range of possible set times based on the desired application. For example, when backfilling trenches in roadway a quick set time is desired providing the set time allows sufficient time to complete filling of the void with the composition. Despite the desire for a quick set time, the ultimate final compressive strength must not exceed the local agency standards, i.e., maintain good removability modulus numbers. In some embodiments, the set time of the composition is determined by measuring penetration resistance with a pocket penetrometer (e.g., with a resistance of 4 psi as typically used in standard ASTM WK 27337) or cement setting time standard ASTM C403. In an embodiment of the present disclosure, the set time for a composition can be between about 8 minutes and about 40 minutes, between about 9 minutes and about 35 minutes, between about 10 minutes and about 30 minutes, between about 11 minutes and about 25 minutes, between about 12 minutes and about 20 minutes, or between about 13 minutes and about 17 minutes. In additional embodiments, a composition has a set time of less than 45 minutes, of less than about 40 minutes, of less than about 35 minutes, of less than about 30 minutes, of less than about 25 minutes, of less than about 20 minutes, of less than about 18 minutes, of less than about 16 minutes, of less than about 14 minutes. In other embodiments, a composition has a set time of greater than about 5 minutes, of greater than about 10 minutes, of greater than about 15 minutes, of greater than about 20 minutes, of greater than about 25 minutes, or of greater than about 30 minutes.

Compositions of the present disclosure will have a range of compressive strengths at various times after the addition of a composition to a void depending on the desired properties of the composition. For example, and similar to set time, a higher earlier compressive strength is advantageous when working when backfilling trenches in a roadway or other highly traveled area. The higher, earlier compressive strength allows for the backfilled void to be patched and reopened to use at an earlier time. Again, despite the desire for a high earlier compressive strength the final compressive strength must not exceed the local agency standards, i.e., maintain good removability modulus numbers.

In certain embodiments, the compressive strength is measured at 1 hour, 2 hours, 4 hours, 1 day, 3 days, 7 days and 28 days where the 28 day measurement is considered the final compressive strength. In other embodiments, the compressive strength is measured more often at smaller intervals. In some embodiments, the compressive strength is measured at 90 days. In an embodiment, the compressive strength or bearing capacity or penetration resistance of a composition is measured at 1 hour, 2 hours, 4 hours, 7 days, and 28 days after backfilling using ASTM WK 27337 or C403.

In an embodiment, the compressive strength of a composition of the present disclosure at 1 hour will be between about 3 psi and about 40 psi, between about 5 psi and about 35 psi, between about 7 psi and about 30 psi. In additional embodiments, the compressive strength of the composition at 1 hour will be greater than about 3 psi, will be greater than about 5 psi, will be greater than about 10 psi, will be greater than about 15 psi, will be greater than about 25 psi, will be greater than about 30 psi, or will be greater than about 40 psi.

In an embodiment, the compressive strength of a composition of the present disclosure at 1.5 hours will be between about 3 psi and about 40 psi, between about 5 psi and about 35 psi, between about 7 psi and about 30 psi. In additional embodiments, the compressive strength of the composition at 1 hour will be greater than about 3 psi, will be greater than about 5 psi, will be greater than about 10 psi, will be greater than about 15 psi, will be greater than about 25 psi, will be greater than about 30 psi, or will be greater than about 40 psi.

In an embodiment, the compressive strength of a composition of the present disclosure at 2 hours will be between about 10 psi and about 40 psi, between about 15 psi and about 35 psi, between about 20 psi and about 30 psi. In additional embodiments, the compressive strength of the composition at 2 hours will be greater than about 10 psi, will be greater than about 15 psi, will be greater than about 20 psi, will be greater than about 25 psi, will be greater than about 30 psi, will be greater than about 35 psi, or will be greater than about 40 psi.

In an embodiment, the compressive strength of a composition of the present disclosure at 4 hours will be between about 10 psi and about 70 psi, 10 psi and about 60 psi, between about 15 psi and about 50 psi, between about 15 psi and about 40 psi, between about 20 psi and about 30 psi. In additional embodiments, the compressive strength of the composition at 4 hours will be greater than about 10 psi, will be greater than about 15 psi, will be greater than about 20 psi, will be greater than about 25 psi, will be greater than about 30 psi, will be greater than about 35 psi, will be greater than about 40 psi or will be greater than about 50 psi. In an embodiment, the compressive strength of a composition of the present disclosure at 4 hours will be less than about 70 psi, less than about 60 psi, less than about 50 psi, less than about 40 psi, less than about 30 psi, or less than about 20 psi.

In an embodiment, the compressive strength of a composition of the present disclosure at 28 days hours will be between about 75 psi and about 300 psi, between about 100 psi and about 250 psi, between about 125 psi and about 200 psi. In additional embodiments, the compressive strength of the composition at 28 days will be greater than about 75 psi, will be greater than about 100 psi, will be greater than about 125 psi, will be greater than about 150 psi, will be greater than about 175 psi, will be greater than about 200 psi, or will be greater than about 250 psi. In certain embodiments, the compressive strength of the composition at 28 days will be less than about 300 psi, less than about 250 psi, less than about 200 psi, less than about 175 psi, less than about 150 psi, less than about 125 psi, or less than about 100 psi.

In an embodiment of the present disclosure, an important consideration is the possible re-excavation of the backfilled composition by standard or ordinary excavation equipment. One measure of how easily a previously backfilled composition can be removed is the Removability Modulus ("RE"). The Removability Modulus is a commonly used industry standard for assigning a value to how easily a backfilled composition can be removed. The lower the RE number the easier the backfilled composition can be re-excavated. The Removability Modulus can be determined by the following formula:

$$RE = \frac{W^{1.5} \times 104 \times C^{0.5}}{10^6}$$

W=in-situ unit weight (pcf)

C=28 day compressive strength (psi)

In an embodiment of the present disclosure, the RE factor of a composition is between about 0.3 and between about 3.0, between about 0.5 and about 2.5, between about 0.7 and about 2.0, between about 0.8 and about 1.8, between about 0.9 and about 1.6, or between about 1.0 and about 1.4.

In additional embodiments of the present disclosure, the RE factor of a composition less than about 2.0, less than about 1.8, less than about 1.6, less than about 1.5, less than about 1.4, less than about 1.2, less than about 1.0, less than about 0.8, or less than about 0.6. In other embodiments of the present disclosure, the RE factor of a composition is greater than about 0.3, greater than about 0.6, greater than about 0.9, greater than about 1.1, greater than about 1.3, greater than about 1.5, or greater than about 1.7.

By using certain compositions of the present disclosure, it is possible to reduce the time from backfilling to paving of the backfilled surface. This reduction in time ultimately reduces the time from backfilling to intended use of the backfilled void, i.e., pedestrian traffic or vehicle traffic. In certain embodiments the backfilled void is suitable for paving (or equivalent) in less than about 4.0 hours, in less than about 3.5 hours, in less than about 3.0 hours, in less than about 2.5 hours, in less than about 2.0 hours, in less than about 1.5 hours, or in less than about 1.0 hour.

In certain embodiments of the present disclosure, a suitable composition can be defined by the water to fly ash ratio, e.g., when using no filler or when using non-cementitious fly ash filler. In these embodiments, a composition can have a range of water to fly ash ratios depending on the water demand of the fly ash, the desired flowability, the desired setting time and the desired final compressive strength. In certain embodiments, the water to fly ash ratio of a composition (W/FA) is between about 0.2 and about 1.0, between about 0.3 and about 0.8, or between about 0.4 and about 0.6. In additional embodiments, the water to fly ash ratio of a composition is greater than about 0.3, greater than about 0.5, greater than about 0.7 or greater than about 0.9. In other embodiments, the water to fly ash ratio is less than about 1.0, less than about 0.8, less than about 0.6, less than about 0.5, or less than about 0.4.

In certain embodiments of the present disclosure, a composition does not include one or more of the following: does not include a water reducer, does not include Portland cement, does not include a set retarder, does not include any cementitious material other than cementitious fly ash, does not include a filler, does not include aggregate, does not include gravel, does not include CaCO or lime other than that present in the cementitious fly ash and/or filler, or does not include sand. Furthermore, a composition of the present disclosure does not include native soils in some embodiments.

In certain embodiments, the flowability of a composition can be determined by a slump test C143 or a slump flow as determined by C1611. A slump spread can equal roughly 2.5 times the D6103 spread, both in inches. In certain embodiments of the present disclosure, the slump cone spread of a composition is between about 10 and about 45 inches, between about 15 and about 40 inches, is between about 20 inches and about 30 inches. In additional embodiments, a composition of the present disclosure has a slump cone spread of less than about 50 inches, of less than about 40 inches, of less than about 35 inches, of less than about 30 inches, or of less than about 25 inches. In certain embodiments, the slump cone spread of a composition is greater than about 20 inches, is greater than about 25 inches, is greater than about 30 inches, is greater than about 35 inches, is greater than about 40 inches, or is greater than about 45 inches.

In additional embodiments, a composition of the present disclosure has a unit weight of between about 20 pcf and about 150 pcf, of between about 40 pcf and about 130 pcf, between about 60 pcf and about 100 pcf. In other embodiments, the unit weight of a composition is greater than about 30 pcf, greater than about 50 pcf, greater than about 70 pcf, greater than about 90 pcf, or greater than about 120 pcf. In still other embodiments, a composition has a unit weight of less than about 130 pcf, of less than about 110 pcf, of less than about 90 pcf, of less than about 80 pcf, of less than about 70 pcf, or of less than about 60 pcf.

The present disclosure also provides for a new method of determining a composition to reduce freeze thaw heave risk. For example, in an embodiment, the present disclosure provides a method for determining a suitable composition for preventing prevent ice lens formation comprising: determining the water demand of each fly ash within the composition; calculating the water demand for a combination of fly ashes; determining the compressive strength and densities for a combination of fly ashes; and determining the amount of air content necessary for the composition to have a compressive strength of between 10 and 60 PSI after 4 hours and a removability modulus of less than 1.8 after 28 days. In an additional embodiment, the method may further include identifying a group of fly ashes for use in the composition prior to determining the water demand of each fly ash within the composition.

In an embodiment, determining the water demand of each fly ash within the composition includes determining the water demand of cementitious fly ashes, specification grade or non-specification grade, as well as non-cementitious fly ashes, specification grade or non-specification grade. In an embodiment, determining the water demand includes adding water to a fly ash to achieve a spread of between about 6 inches and about 14 inches using a D6103 spread test. In additional embodiments, determining the water demand includes adding water to a fly ash to achieve a spread of between about 8 inches and about 12 inches or about 10 inches using a D6103 spread test. In some embodiments, determining the water demand includes plotting different water to fly ash ratios as a function of spread, e.g., as seen in FIG. **9**.

Calculating the water demand for a combination of fly ashes can be determined in a number of fashions. In an embodiment, the water demand can be calculated for a combination of ingredients, including fly ashes and additional fillers, i.e., sand. In a specific embodiment, the water demand for a specific combination is determined by reference to the individual water demand of each fly ash or filler. For example, if a cementitious fly ash needs a 0.35 water/fly ash ratio to achieve a 10 inch spread and a non-cementitious fly ash needs a 0.48 water/fly ash ratio to achieve a 10 inch spread, then the total water demand for the combination of these two ingredients to have between a 8 and 12 inch spread is determined based on the known water demand for each fly ash and the proportion of each fly ash within the composition.

In an embodiment, determining the compressive strength and densities for a combination of fly ashes may include using ASTM C495 and C138 or other common tests in the industry. In this disclosure compressive strengths were measured using ASTM C495. In alternative embodiments, the compressive strength is determined using other methods apparent to one of skill in the art. In some embodiments, determining the compressive strength and densities for a combination of fly ashes includes plotting the results of compressive strength testing as a function of the water to fly ash ratio.

Determining the amount of air content necessary to achieve a predetermined compressive strength and removability modulus can include testing various or the same combination of fly ash and/or filler with various air contents to determine the air content necessary to achieve a desired compressive strength and/or removability modulus.

The present disclosure also provides for a novel method of backfilling a void. For example, in an embodiment, the present disclosure provides a method of backfilling a void to prevent ice lens formation comprising: mixing cementitious fly ash and filler to a predetermined ratio; adding water to the mix of cementitious fly ash and filler to make a wet mixture; adding air to the wet mixture, wherein the predetermined mix of cementitious fly ash and filler, the addition of water and the addition of air makes a composition having a compressive strength of between 10 and 60 PSI after 4 hours and a removability modulus of less than 1.8 after 28 days; and adding the composition to a void. In an additional embodiment, the method may include determining that the void is subject to freezing prior to mixing cementitious fly ash and filler to a predetermined ratio. If the void is not subject to freezing, a composition of the present disclosure provides an advantageous early set time and early strength while still maintaining a low RE by addition of air.

Mixing cementitious fly ash and filler to a predetermined ratio can include pre-mixing the dry ingredients prior to arriving at the construction site or mixing the dry ingredients at the construction site. In an embodiment, the composition does not have a filler.

In an embodiment, the addition of water to the mix of cementitious fly ash and filler occurs at the construction site. However, in other embodiments, the water is added prior to arrival at the construction site, e.g., in the drum of a ready mix truck. The addition of water may occur inside the drum of a volumetric mixing truck or may occur as the dry mix leaves or after the dry mix has left the mixing truck, e.g., while the dry mix is moving thru a spiral auger.

In some embodiments, the addition of air to the wet mixture can occur simultaneously with the addition of water to the dry ingredients or after the addition of water to the dry ingredients. In some embodiments, a cellular foam providing the air content is placed directly onto a wet mixture comprising the cementitious fly ash, filler and water. In other embodiments, the air content is provided by the addition of a dry surfactant to the cementitious fly ash and/or filler prior to addition of water or by using a liquid air entraining admixture during mixing.

In several described embodiments, the completion of the backfill composition occurs at the construction site, e.g., by addition of water and/or air content; however, in other embodiments, the water, air content (e.g., cellular foam), cementitious fly ash and/or filler may be premixed offsite. In this embodiment, a slower set time—thereby allowing transportation of the premixed composition to the construction site—can be achieved using a retarding agent. In an embodiment, the retarding agent is citric acid or boric acid (or a combination thereof) while in other embodiments the retarding agent is any agent capable of retarding the set time of the composition.

The addition of the composition to the void can be achieved using buckets, chutes, pumps, conveyors, hoses, augers or any method routinely used with Portland cement based compositions.

Referring now to the figures, FIG. **1** illustrates the creation of horizontal cracks by a small compactor on a backfilled trench as a matter of time and depth. The illustrated trench is roughly 8 ft deep from the surface of the backfill **100** to the bottom of the trench **102**. The native soil **104** sits under the trench. A small compactor **106** begins to compact the asphalt trench patch along the surface **100** at different times after the composition (Mix B) is placed in the trench. With earlier starting times (e.g., 2.0 hours or 4.0 hours), the vibration can create horizontal fractures **118** deeper, since the strength of the backfill near the surface cannot dissipate the vibrations as well (e.g., to a depth of 5.5 feet if starting at 2.0 hours and depth of 4.0 feet if starting at 4.0 hours). As the composition becomes stronger over time, fractures **118** that result from the small compactor **106** are nearer the surface and do not extend as deep. With a starting time (e.g., 12 hours) that allows sufficient strength in the composition to resist all horizontal fractures, pavement replacement can safely occur. An attempt to replacement pavement at any time earlier than 12 hours results in horizontal crack formation, which can ultimately lead to frost heave, due to ice lens development.

FIG. **2** illustrates a larger, heavier, more powerful compactor as discussed in FIG. **1**. Like FIG. **1**, the illustrated trench is roughly 8.0 ft deep from the surface of the backfill **100** to the bottom of the trench **102**. The native soil **104** sits under the trench. A large compactor **108** begins to compact the asphalt trench patch along the surface **100** at different times after the composition (Mix B) is placed in the trench. With earlier starting times (e.g., 2 hours or 4 hours), the vibration can create horizontal fractures **118** deeper, since the strength of the backfill near the surface cannot dissipate the vibrations as well (e.g., to a depth of 8.0 feet if starting at 2 hours and depth of 7.0 feet if starting at 4 hours). As the composition becomes stronger over time, fractures **118** that result from the large compactor **108** are nearer the surface and do not extend as deep. With a starting time (e.g., greater than 14 hours) that allows sufficient strength in the composition to resist all horizontal fractures, pavement replacement can safely occur. An attempt to replace pavement at 14 hours or earlier in this hypothetical example results in horizontal crack formation, which can ultimately lead to frost heave. In this figure, with the same mix as FIG. **2**, fractures are generated deeper with any given start time with a larger compactor.

FIG. **3** illustrates the previously depicted small compactor **106** of FIG. **1** and the same conditions as FIG. **1** but uses a different composition, i.e., Mix A, to fill the trench. Mix A sets up and hardens faster than the Mix B used in FIG. **1** and FIG. **2**. At a faster setting time due to a faster setting composition, the small compactor **106** will induce shallower horizontal fracture at any given start time, e.g., 3.0 feet at 2 hours and 2 feet at 4 hours. With a faster setting Mix A, the safe starting time has been reduced from 12-hours (e.g., FIG. **1**) to 8-hours using hypothetical Mix A over Mix B.

FIG. 4 illustrates the previously depicted large compactor **108** of FIG. **2** and the same conditions as FIG. **2** but uses a different composition, i.e., Mix A, to fill the trench. Mix A sets up and hardens faster than the Mix B used in FIG. **1** and FIG. **2**. At a faster setting time due to a faster setting composition, the large compactor **108** will induce shallower horizontal fracture at any given start time, e.g., 5.0 feet at 2 hours and 4.0 feet at 4 hours. With a faster setting Mix A, the safe starting time has been reduced from greater than 14 hours (e.g., FIG. **2**) to 14 hours using hypothetical Mix A over Mix B.

FIG. **5** illustrates a backfilled trench **120** that has been paved **116** to match the surrounding surface pavement **114**. However, the paving occurred too soon and induced horizontal fractures **118** to the bottom of the trench **102** or to a depth above the bottom of the trench **103**, both above and below the frost line **112**. The previously described horizontal fractures **118** (e.g., FIGS. **1-4**) are a result of paving occurring at a time from backfill when the backfill composition had insufficient strength to resist horizontal shear forces. These fractures **118** can occur below the local depth of frost penetration **112** in a severe winter, depending on the mixture and the compaction time/equipment.

FIG. **6** illustrates a backfilled trench **120** of FIG. **5** following a freeze cycle. The horizontal fractures **118** of FIG. **5** had become saturated with infiltrating water—from the surface and/or ground water (e.g., **122**)—and expanded after the first freezing cycle to become larger fractures **124**. The 11% expansion of water from freezing has enlarged the horizontal fractures **124** above the depth of frost penetration. The resulting enlargement/expansion of the horizontal fractures **124** has caused frost heave, pushing the original backfilled trench pavement **116** above the surrounding surface pavement **114**.

FIG. **7** illustrates a backfilled trench **120** of FIGS. **5** & **6** following several freeze thaw cycles. The horizontal fractures **118** of FIG. **5** have become saturated with infiltrating water (e.g., **122**) and expanded after multiple freezing cycles to become larger fractures **126**. The 11% expansion of water from freezing has enlarged the horizontal fractures **126** above the depth of frost penetration. The resulting enlargement/expansion of the horizontal fractures **126** has worsened the frost heave of FIG. **6**, pushing the original backfilled trench pavement **116** even farther above the surrounding surface pavement **114**. The height of heave of the pavement patch (e.g., height between **116** and **114**) is approximately equal to the sum of the thicknesses of all ice lenses formed in the compaction fractures below **126**.

FIG. **8** illustrates strength development curves for two different hypothetical compositions (e.g., Mix **1** and Mix **2**) without air entrainment, based on both compressive strength (psi), the maturity method (degree-hours), as well as the depth of fracturing of these two mixtures with a compactor (same for both) as a function of starting time. Mild compaction problems **124** (e.g., fractures are shallow and less than 1 foot), moderate compaction problems **126** (e.g., fractures extend to a depth of 3 feet) and severe compaction problems **128** (e.g., fracture extend to a depth of 5 feet) are determined by looking plotting the depth of horizontal fractures as a function of time. Even mild compaction problems can result ice lens formation and frost heave.

Still generally referring to FIG. **8**, in an embodiment, the first step in reducing freeze-thaw heave risk with backfilled trenches is to conduct an on-site test with a given compactor and a given composition. In time, various size ranges of compactors can be tested and in an embodiment of the present disclosure quantified into groups, e.g., small, medium and large, based on test results and manufacturer's output ratings of compactive energy. Similarly, in an embodiment of the present disclosure, compositions can be qualified, e.g., slow, medium, fast and extra fast, based on the time to achieve a specified strength level, i.e., 4-hour/200 psi mix. Such equipment and mix categories can facilitate proper ordering and placement of the correct composition, while successfully reducing freeze-thaw heave risk.

For example, a suitably-sized test trench is excavated and filled with a composition of the present disclosure, as indicated by Mix **1** in FIG. **8**. Maturity probes are inserted at various depths in the composition and activated at the time of placement.

At various times along the length of the backfilled trench, the compactor is operated for a suitable number of passes to properly compact asphalt. The next day, coring is performed to determine the depth of compaction fractures associated with the different starting times. These fracture depths vs. starting-times are plotted on a graph, as shown in FIG. **8**. Typically, the safe starting time for any given compactor & mixture combination would be the first time that no compaction fractures can occur. However, pavement patch materials could be compacted if the depth of the patch materials exceeds the local frost depth; any compaction fractures below the final frost depth would not contribute to deleterious heaving.

Still referring to FIG. **8**, based on previously performed laboratory testing of Mix **1**, the strength development versus time curve can be graphed as show in FIG. **8**, both in terms of compressive strength (psi), and Maturity Values (degree-hours) recorded in a test cylinder. With this correlation data, the compositions' actual strength (150 psi) in the trench experiment can be properly estimated, based on the maturity probes in the trench fill (400 degree-hours) and using the correlation graph. While the maturity values from test cylinders at a given time will not match the trench values at the same time, (due to heat-generation of mass-effects of samples), the trench values can be used on the graph to determine the time/strength mixture needed. Thus, strength required to resist compaction fractures can readily be determined to specify mixture performance vs. a desired starting time.

Still referring to FIG. **8**, the hypothetical required compressive strength was determined to be 150 psi, and the safe starting time for Mix **1** was 13 hours. If this was too long to repair the trench and open the street to traffic, a faster mix could be selected. Based on a similar strength-development curve for Mix **2**, 150 psi should be achieved (under laboratory conditions) within 3.75 hours, although at a different Maturity value (600 degree-hours) than Mix **1** exhibited at 150 psi. Hence, a safe starting time for compaction would be field—verified when the maturity probes in the trench filled with Mix **2** achieve the required degree-hour value corresponding to 150 psi for Mix **2** (600 degree-hours).

FIG. **9** illustrates graphically the results of testing different fly ashes at different W/FA ratios to determine the resulting fluidity using ASTM D6103. The following cementitious fly ashes were tested: Gentleman **136**, California **140**, and Arapahoe **144**. In addition, Valmont Class F fly ash **142** was tested. In this case, the spread was determined by lifting an open-ended 3 inch diameter by 6 inch tall cylinder mold (ASTM D6103). This size is convenient for smaller laboratory batches and can be reasonably correlated to using a 12 inch high concrete slump cone as typical for self-consolidating concrete mixtures. As shown in the graph, different fly ashes have different "water demand" curves (e.g., **136**, **140**, **142**, and **144**), to achieve a desired fluidity; in this case, a 10" spread **132** is desired, with maximum spread of 12 inches **134** and a minimum spread of 8 inches **130**. The graphs can be used to estimate the W/FA ratio at the exact spread desired. For example, the desired W/FA ratio for a 10 inch spread of California Class C ash **136** is roughly 0.26 as indicated by the intersection point **138** of the California Class C ash graph **136** with the 10 inch spread line **132**. The same determination is possible for the other graphed fly ashes, e.g., **138**, **148** and **146**.

FIG. **10** illustrates typical 4-hour compressive strengths of various cementitious fly ashes as a function of their W/FA ratios. After strength testing has occurred, the estimated strength at the W/FA ratio associated with their desired 10 inch spread can be estimated from the chart. For example, at a 10 inch spread, Arapahoe **151** has a strength of 125 psi as indicated by the circle at **153**. For example, at a 10 inch spread, California **152** has a strength of 200 psi as indicated by the circle at **155**. For example, at a 10 inch spread, Gentlemen **150** has a strength of 320 psi as indicated by the circle at **157**.

FIG. **11** illustrates how testing the water demand of each fly ash (cementitious or non-cementitious) separately can be useful in determining the estimated 4-hour strength of various blends of Class C & F fly ashes. In this case, depending on the blend, the W/FA ratio of the blend is first mathematically estimated. Since the non-cementitious fly ash does not influence early strengths, the estimated blended W/FA can be used with the strength-W/FA curve for the cementitious fly ash to estimate the blended strength. For example, a 50-50% blend of Gentleman and Valmont is estimated with a W/FA ratio of 0.39, resulting in 120 psi at 4-hours.

FIG. **12** illustrates the strength vs. time curve taught by the ’422 patent **166**. One way to reach higher early strengths would be to use higher cementitious fly ash blends and/or lower water contents; however these would result in ultimate strengths greater than desired or allowed by ACI 229. For example, a 1:1 Gentleman to Valmont blend **164** results in earlier higher strengths but ultimately results in a final strength above that recommended by ACI 229, represented by **160**.

FIG. **13** illustrates strength curves at varying air contents, created by adding increasing amounts of cellular foam to compositions of the present disclosure. For example, a composition of the ’422 patent with no cellular foam **176**, a composition of the present disclosure entrained with cellular foam resulting in 14% air **172**, a composition of the present disclosure with no air **170**, a composition of the present disclosure entrained with cellular foam resulting in 28% air **174**, a composition of the present disclosure entrained with cellular foam resulting in 33% air **177**, a composition of the present disclosure entrained with cellular foam resulting in 41% air **178** and a composition of the present disclosure entrained with cellular foam resulting in 54% air **179**.

Still referring to FIG. **13**, the optimization process will include balancing higher early strengths and acceptable ultimate strengths. In this case, a moderately-reacting cementitious fly ash (Arapahoe) was used without air entrainment or with varying degrees of air entrainment, mimicking the early strengths of the ’422 non-air formulation **176**. In alternative embodiments, more reactive fly ashes (such as Gentleman) can be used to achieve faster-setting times and higher-early strengths, but still effectively limited ultimate strengths with sufficiently high air contents.

Laboratory and field testing has shown that the setting time is comparable with various air contents; however the initial early strengths are affected by higher air contents, which can impact early placement of street repair patches.

TABLE 1

Arapahoe-Valmont 50-50 Mixes, varying air content							
UW	% Air	41-Hour	1-day	7-day	28-day	RE	FIG. 13 No.
101	0	56	88	142	200	1.50	170
87	14	56	125	155	182	1.14	172
73	28	38	54	81	136	0.75	174
68	33	25	48	75	70	0.49	177
60	41	<20 (14)	33	36	41	0.31	178
46	54	<20 (9)	<20 (16)	24	26	0.17	179

As shown in the table above, the RE of foamed compositions decreases with increased air-contents, both because of lower unit weights and lowered compressive strengths. Field trials with compositions foamed to various air contents, then later excavated with a tractor backhoe confirmed the relative ease of removing hardened compositions with higher air.

FIG. **14** illustrates a hypothetical graph, in an embodiment, demonstrating the compressive strength as a function of time for compositions with varying air content. For example, a composition of the ’422 patent with no cellular foam **188**, a composition of the present disclosure with no air **180**, a composition of the present disclosure with low air content **182**, a composition of the present disclosure with medium air content **184**, a composition of the present disclosure with high foam content **186** and a composition of the present disclosure with too much air content **190**. The ACI 229 strength limit is represented by **160**.

FIG. **15** illustrates an embodiment of a method **200** of the present disclosure. To increase the field performance and lab predictability of test results, a better mix design & testing protocol was needed. At step **202**, fly ashes of interest are tested separately for consistency versus water demand. Test results of slump-cone and/or 3×6 cylinder spreads (inches) will be graphed at varied water contents somewhat above, at, and somewhat below the desired consistency of the composition (e.g. FIG. **9**). A curve can be fit through the measured data points, and a specific water demand can be determined at the desired consistency (e.g., a 26 inch cone-spread or 10 inch cylinder spread). In addition, at step **202**, the water demand for a filler other than non-cementitious fly ash can be determined. At step **204**, the estimated water demand of a composition, i.e., 30% cementitious fly ash and 30% non-cementitious fly ash, is determined by proportioning of the separate water demands determined in step **202**.

At step **206**, the compressive strengths and densities of a composition is determined. Compressive strength versus time testing is performed on various compositions, e.g., same composition with different water/fly ash ratios, to determine the compressive strengths at different water contents. These tests can range from a composition with using only cementitious fly ash at the desired consistency to a composition with the highest water demand estimated for the blend of cementitious fly ash and non-cementitious fly ash or filler). Since the final resulting compressive strength of the blended fly ash mixture is dependent on the actual water/fly ash ratio acting on the cementitious material, compressive strengths of any suggested blend can be estimated to determine if further verification testing of the blend is warranted.

At step **210**, the amount air content needed for composition from step **206** to have a desired RE is determined. For example, a composition from step **206** may set in the desired time, e.g., 30 minutes, but may have a high final compressive strength resulting in a high RE. Thus, the amount of air content, e.g., cellular foam, necessary to reduce the final compressive strength is determined. In some embodiments, the final compressive strength and unit weight is retested after determining the final air content.

The time of initial set is determined when the weight of the pocket penetrometer (approximately 0.2 lb) was supported by the surface of the composition on a diameter of 0.25 inch; this represents a penetration pressure of approximately 4.0 psi. Further values are measured by pushing the penetrometer into the fly ash mixture.

FIG. **16** illustrates an embodiment of a method **220** presently disclosed. At step **222**, the dry ingredients are combined to a desired ratio. In an embodiment, the dry ingredients comprise cementitious fly ash and non-cementitious fly ash. In additional embodiments, the dry ingredients comprise cementitious fly ash, non-cementitious fly ash and additional fillers, e.g., sand. In some embodiments, the dry ingredients are only cementitious fly ash. In other embodiments, the dry ingredients do not contain non-cementitious fly ash. In an embodiment, step **222** occurs offsite, i.e., not at the construction site.

At step **224**, water is added to the dry ingredients. At step **226**, air is added to the wet mixture, e.g., cellular foam is added to the wet mixture. At step **228**, the wet mixture with air content is added to the desired void resulting in a backfill composition stronger than native soils and structural fills but not harder to excavate.

FIG. **17** is a picture of ice lens formation in a composition of the '422 patent. A 3.75 inch diameter core **230** was taken from backfill using a composition as taught by the '422 patent. The larger, lower ice lens **232** is 0.40 inches thick. The ice lenses **232** formed by the subsequent filtration of water into the horizontal cracks in the backfill composition combined with multiple freeze thaw cycles. In FIG. **17**, multiple ice lenses of varying thicknesses have formed in the horizontal cracks of the backfill.

FIG. **18** is a picture of a road surface patch **242** over a backfill composition as taught by the '422 patent. As is evident from the picture, ice lens formation has caused frost heave **244** and the patch **242** rising above the surrounding pavement **248**. A blackberry cellular phone **246** provides reference.

Although embodiments of the present disclosure have been described with respect to backfilling a trench to prevent ice lens formation and quicker return to use of the backfilled area, it should be appreciated that the principles of the present disclosure can also be applied to filling voids due to pipe abandonment, annular spaces, undercut areas, and other void filling applications. It should also be appreciated that the principles of the present disclosure can also be applied to providing structural support for utilities, replacement of unstable subgrade during pavement repairs and similar applications.

The foregoing description of the exemplary embodiments of the disclosure has been presented for the purposes of illustration and description. They are not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the disclosure be limited not with this detailed description, but rather by the claims appended hereto.

EXAMPLES

The weight of the ingredients in the following examples have been normalized to provide one cubic yard of final composition. That is, the actual amounts used in the examples have been proportionally increased or decreased based on the final volume achieved to one cubic yard. For example, if a laboratory batch of 25 lbs cementitious fly ash and 8 lbs of water yielded a final volume of 0.01 cubic yard, the example would be reported below as 2,500 lbs fly ash and 800 lbs water.

Example 1

A 1.5:1 (non-cementitious/cementitious) mix composition of the following components was prepared using a mixing truck: 685 lbs of cementitious fly ash ASTM C618 class C from Excel Energy Pawnee Station; 1031 lbs of non-cementitious fly ash from Excel Energy Cherokee Station; 652 lbs of city water; and 4.7 cubic feet of cellular foam from GEOFOAM SNP (synthetic non-permeable foam), C796 and C869.

The composition had the following physical properties: Time to set was approximately 15 minutes; the spread (ASTM D6103) was 9.5 inches; the slump-cone spread was approximately 26 inches; the air content was 18%; the unit weight was 88 pcf; and the water/fly ash ratio was 0.38.

The composition has the following compressive strengths: 30 psi at four hours; 40 psi at one day; 166 psi at seven days; and 274 psi at 28 days. The composition had a removability modulus of 1.42.

Example 2

A 1.5:1 (non-cementitious/cementitious) mix composition of the following components was prepared using a mixing truck: 644 lbs of cementitious fly ash ASTM C618 class C from Excel Energy Pawnee Station; 970 lbs of non-cementitious fly ash from Excel Energy Cherokee Station; 613 lbs of city water; and 6.1 cubic feet of cellular foam from GEOFOAM SNP (synthetic non-permeable foam), C796 and C869.

The composition had the following physical properties: Time to set was approximately 15 minutes; the spread (ASTM D6103) was 14 inches; the slump-cone spread was approximately 35 inches; the air content was 23%; the unit weight was 83 pcf; and the water/fly ash ratio was 0.38.

The composition has the following compressive strengths: 19 psi at four hours; 32 psi at one day; 91 psi at seven days; and 151 psi at 28 days. The composition had a removability modulus of 0.96.

Example 3

A 2:1 (non-cementitious/cementitious) mix composition of the following components was prepared in a laboratory: 572 lbs of cementitious fly ash ASTM C618 class C from Excel Energy Pawnee Station; 1145 lbs of non-cementitious fly ash from Excel Energy Cherokee Station; 687 lbs of city water; and 4 cubic feet of cellular foam from GEOFOAM SNP (synthetic non-permeable foam), C796 and C869.

The composition had the following physical properties: The spread (ASTM D6103) was 10 inches; the slump-cone spread was approximately 26 inches; the air content was 15%; the unit weight was 86 pcf; and the water/fly ash ratio was 0.40.

The composition has the following compressive strengths: 22 psi at seven days; and 142 psi at 28 days. The composition had a removability modulus of 0.99.

Example 4

A 3:1 (non-cementitious/cementitious) mix composition of the following components was prepared in the laboratory: 390 lbs of cementitious fly ash ASTM C618 class C from Excel Energy Pawnee Station; 1171 lbs of non-cementitious fly ash from Excel Energy Cherokee Station; 734 lbs of city water; and 4.1 cubic feet of cellular foam from GEOFOAM SNP (synthetic non-permeable foam), C796 and C869.

The composition had the following physical properties: The spread (ASTM D6103) was 10 inches; the slump-cone spread was approximately 26 inches; the air content was 15%; the unit weight was 85 pcf; and the water/fly ash ratio was 0.47.

The composition has the following compressive strengths: 55 psi at seven days; and 123 psi at 28 days. The composition had a removability modulus of 0.90.

Example 5

A composition of the following components was prepared in the laboratory: 732 lbs of cementitious fly ash ASTM C 618 class C from Excel Energy Pawnee Station; 932 lbs of non-cementitious fly ash from Excel Energy Cherokee Station; 699 lbs of city water; and 4.9 cubic feet of cellular foam from GEOFOAM SNP (synthetic non-permeable foam), C796 and C869.

The composition had the following physical properties: The spread (ASTM D6103) was 11 inches; the slump-cone spread was approximately 28 inches; the air content was 18.2%; the unit weight was 87.5 pcf; and the water/fly ash ratio was 0.42. The composition has the following compressive strengths: 5 psi at four hours; 38 psi at one day; 126 psi at seven days; and 157 psi at 28 days. The composition had a removability modulus of 1.06.

Example 6

In example 6, the following compositions were prepared for comparison as displayed in Table 2 and 3.

TABLE 2

The comparison of 9 different compositions with values in pounds per cubic yard unless otherwise indicated, e.g., air.

Mix No.		Cementitious fly ash	Non-cementitious fly ash	Additional Filler (e.g., Sand)	Water	Total	% Air
1	Truck	685	1031		652	2368	18
2	Truck	644	970		613	2227	23
3	Lab	572	1145		687	2404	15
4	Lab	390	1171		734	2295	15
5	Lab	732	932		699	2363	18
6	Lab	1350			405	1755	46
7	Lab	831			249	1080	67
8	Lab	1170			585	1755	40
9	Lab	720			360	1080	63

TABLE 3

Is an extension of Table 2 with the same compositions as Table 2 but with values in percent by weight and including the 28 day compressive strength data and RE for each composition.

Mix No.		Cementitious fly ash	Non-cementitious fly ash	Additional Filler (e.g., Sand)	Water	% Air	28 day Compressive Strength (PSI)	RE
1	Truck	29%	44%	0%	28%	18	275	1.42
2	Truck	29%	44%	0%	28%	23	151	0.96
3	Lab	24%	48%	0%	29%	15	142	0.99
4	Lab	17%	51%	0%	32%	15	123	0.90
5	Lab	31%	39%	0%	30%	18	157	1.06
6	Lab	77%	0%	0%	23%	46	552	1.29
7	Lab	77%	0%	0%	23%	67	120	0.29
8	Lab	67%	0%	0%	33%	40	355	1.00
9	Lab	67%	0%	0%	33%	63	81	0.25

Mix numbers 1 through 5 of Example 6 (e.g., Table 1 and Table 2) are compositions comprising cementitious fly ash, non-cementitious fly ash, water and cellular foam to provide air content. Mix numbers 6 through 9 are compositions containing no filler, no non-cementitious fly ash or otherwise, with water and cellular foam.

What is claimed is:

1. A composition for preventing ice lens formation consisting essentially of:

between 5% and 75% air by volume;

between 20% and 90% class C fly ash by weight; and

between 15% and 60% water by weight;

wherein the composition has a time to set of less than 40 minutes, a compressive strength of between 10 and 100 PSI after 4 hours, and a removability modulus of less than 1.8 after 28 days.

2. The composition of claim **1**, wherein the air is between 30% and 70% by volume of the composition.

3. The composition of claim **1**, wherein the class C fly ash is between 30% and 80% by weight of the composition.

4. The composition of claim **1**, wherein the water is between 20% and 40% by weight of the composition.

5. The composition of claim **1**, wherein the water is between 25% and 35% by weight of the composition.

6. The composition of claim **1**, wherein the set time is less than 30 minutes.

7. The composition of claim **1**, wherein the set time is less than 20 minutes.

8. The composition of claim **1**, wherein the removability modulus is less than 1.5 after 28 days.

9. The composition of claim **1**, wherein the removability modulus is less than 0.8 after 28 days.

10. The composition of claim **1**, wherein

the air is between 30% and 70% by volume;

the class C fly ash is between 30% and 80% by weight; and

the water is between 20% and 40% by weight.

11. The composition of claim **1** or **10**, wherein the water to class C fly ash ratio is between 0.35 to 0.50.

12. The composition of claim **1** or **10**, wherein the volume of air results from an air entraining agent.

13. The composition of claim **12**, wherein the air entraining agent is a cellular foam.

14. A composition for preventing ice lens formation consisting essentially of:

between 10% and 60% air by volume;

between 10% and 60% of class C fly ash by weight;

between 15% and 75% of class F fly ash by weight; and
between 20% and 60% water by weight;
wherein the composition has a time to set of less than 40 minutes, a compressive strength of between 10 and 100 PSI after 4 hours, and a removability modulus of less than 1.8 after 28 days.

15. The composition of claim **14**, wherein
the air is between 15% and 50% by volume;
the class C fly ash is between 15% and 50% by weight;
the class F fly ash is between 30% and 65% by weight; and
the water is between 25% and 40% by weight.

16. The composition of claim **14**, wherein
the air is between 20% and 40% by volume;
the class C fly ash is between 15% and 40% by weight;
the class F fly ash is between 30% and 55% by weight; and
the water is between 25% and 35% by weight.

17. The composition of claim **14**, wherein
the air is between 20% and 60% by volume;
the class C fly ash is between 30% and 60% by weight;
the class F fly ash is between 15% and 40% by weight; and
the water is between 25% and 50% by weight.

18. The composition of claim **14**, wherein
the air is between 30% and 60% by volume;
the class C fly ash is between 35% and 55% by weight;
the class F fly ash is between 15% and 35% by weight; and
the water is between 25% and 40% by weight.

19. The composition of claim **14**, **15**, **16**, **17**, or **18**, wherein the volume of air results from an air entraining agent.

20. The composition of claim **19**, wherein the air entraining agent is a cellular foam.

21. A composition for preventing ice lens formation consisting essentially of:
between 10% and 60% air by volume;
between 10% and 60% of class C fly ash by weight;
between 15% and 75% of class F fly ash by weight;
between 20% and 60% water by weight; and
between 0.01% and 2.0% set retarder by weight;
wherein the composition has a time to set of less than 4 hours, a compressive strength of between 0 and 80 PSI after 4 hours, and a removability modulus of less than 1.5 after 28 days.

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